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FIXATION AND AVAILABILITY OF AMMONIUM

IN SOME ALBERTA SOILS

by



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B.Sc.

A THESIS SUBMITTED TO

THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR

THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

FALL, 1971





UNIVERSITY OF ALBERTA  
FACULTY OF GRADUATE STUDIES  
AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "Fixation and Availability of Ammonium in Some Alberta Soils" submitted by Hanns-Gunther Jahn, B.Sc., in partial fulfilment of the requirements for a degree of Master of Science.



## ABSTRACT

Surface samples (0-15 cm) from 101 cultivated soils of the Dark Brown, Black and Gray Wooded soil zones of central and northern Alberta were analyzed for ammonium fixing capacity under wet conditions. This capacity ranged from 4 to 112 ppm ammonium N for 100 soils and was 260 ppm for one soil. For 11 soils average fixation was 3, 10 and 27 ppm from additions of ammonium N at 35, 140 and 560 ppm, respectively. This fixation increased three-fold after drying at 30° C.

Dry matter yield and uptake of N by rape in the greenhouse was higher from added nitrate than from ammonium on 12 soils. Ammonium fixing capacities were correlated with mean differences between the two sources of N for dry matter yield ( $r = 0.48$ ) and for nitrogen uptake ( $r = 0.49$ ). Incubation of the treated soils yielded higher nitrate contents from added nitrate than from added ammonium. Correlation of ammonium fixing capacities with mean differences in soil nitrate content between the two sources of N was highly consistent ( $r = 0.89$ ).

Oats showed higher tolerance than rape to 84 ppm ammonium N in culture solution. At 3.5 and 7.0 ppm N the yield of rape was the same for ammonium as for nitrate N but was in favor of nitrate at the 14.0 ppm level.



## ACKNOWLEDGEMENTS

The author wishes to express sincere appreciation to the following:

To Dr. G. R. Webster, Department of Soil Science, for his patience and encouragement during this study and for critical review of the manuscript.

To Dr. M. Nyborg, Department of Soil Science, for his interest and assistance in the project.

To Dr. Z. P. Kondra and Dr. G. M. Coen, Department of Plant Science and Canada Department of Agriculture (Alberta Pedology Section), respectively, for reviewing the manuscript and serving on the Thesis Committee.

To the Department of Soil Science and the National Research Council of Canada for financial assistance during the course of this study.





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## INTRODUCTION

The fixation of ammonium nitrogen by the mineral fraction of soils is a rather common reaction. This fixation is an inorganic transformation which renders the ion nonextractable with ordinary cation exchange methods. Ammonium fixation can be of practical importance from the standpoint that the ability of a soil to fix ammonium might influence its nitrogen economy. Many investigations have been conducted on the magnitude of fixation and on the availability of the fixed ion to soil microorganisms and to agricultural plants.

Ammonium fixation in Alberta soils has been studied on a limited number of samples representing the major soil zones of the province (Moore, 1965). This study showed that the ability of surface soils to fix added ammonium varied greatly between samples within each of the soil zones and that appreciable amounts of indigenous fixed ammonium were present in all horizons of profiles from the Brown, Black, and Gray Wooded soil zones.

The current study involved one hundred samples of surface soils. Of these about one half had been collected in the Peace River area in 1963 and 1964 and were made available for this study. The remaining samples were obtained in 1969 from sites of various fertility projects of the Department of Soil Science, so that the total number of samples represented a range of soils of the Dark Brown, Black, and Gray Wooded soil zones of Alberta.





The purpose of this investigation was to establish an inventory of the capacities of surface soils in Alberta to fix added ammonium. From this inventory, a suitable number of soils were to be selected for the following studies:

- (a) The fixation of ammonium when applied at rates encompassing those used for crop production under field conditions.
- (b) The availability of fixed ammonium to soil microorganisms by testing nitrification in ammonium and nitrate treated soils incubated for a suitable period of time.
- (c) The utilization of fixed ammonium by an agricultural crop by growing rape in ammonium and nitrate fertilized soils in the greenhouse.

In addition, a solution culture experiment was to be conducted to study the uptake of ammonium and nitrate nitrogen by rape which had been chosen as the indicator crop for the greenhouse experiments.



## REVIEW OF LITERATURE

### A. Definition of fixation

The Soil Science Society of America (1970) approved the definition of ammonium fixation as "the absorption or adsorption of ammonium ions by the mineral or organic fraction of the soil in a manner that they are relatively insoluble in water and relatively unexchangeable by the usual methods of cation exchange." However, it is well established that the extent to which ammonium ions are removed by cation exchange methods depends largely on the nature of the cation employed and that the replacement of fixed ammonium by other cations is effectively blocked by the presence of small amounts of potassium (Allison and Roller, 1955b; Hanway et al., 1957; Nommik, 1957). Thus, the concept of fixed ammonium is somewhat arbitrary. It would be foremost desirable to find a procedure which would enable a sharp separation between the readily exchangeable and the nonexchangeable ammonium. Barshad (1951) pointed out that the replaceability of ammonium ions depends on the method of replacement, and he proposed that fixed ammonium be defined as adsorbed ammonium which is not replaceable by potassium. But this definition is inadequate, as Scott et al. (1960) found that it is necessary to specify the conditions of the treatment even when potassium is used as the replacing cation. Furthermore, Schiller and Walicord (1964), after obtaining lower values of fixation on prolonged contact of the sample with the extracting solution, drew attention to the need for a conventional method for the determination of ammonium fixation in soils.



A procedure that currently has been widely accepted in studies on the ammonium fixing properties of soils involves the extraction of exchangeable ammonium with 1 N KCl (Hanway and Scott, 1956; Nommik, 1957; Leggett and Moodie, 1962; Rich and Lutz, 1965; Schreven, 1963, 1968). Studies on a wide variety of soils have shown that, when extraction is performed by an equilibrium method with an adequate amount of the replacing cation, the values for exchangeable ammonium using neutral 1 N KCl are in close agreement with those obtained with 1 N KCl at pH 1.0 (Bremner, 1959).

More recently, neutral KCl extractants have been used at concentrations above normality. Schiller and Walicord (1964) reported ammonium fixation on the basis of leaching and filtration with 1.67 N KCl and Nommik (1966) made extractions for exchangeable ammonium with 2 N KCl. Bremner (1965) stated that results using 2 N KCl for the extraction of exchangeable ammonium from soils were identical to those obtained using 1 N KCl. He proposed an equilibrium extraction method in which the soil sample is shaken with 2 N KCl for one hour using 10 ml of this reagent per gram of soil. This method is based on the finding that extractions with 2 N KCl yielded highly reproducible results.

Thus, exchangeable ammonium should be defined as ammonium extracted by the Bremner method and, likewise, fixed ammonium would be defined as ammonium not extractable with 2 N KCl under the standardized conditions.





## B. Mechanism of fixation

Several clay minerals have been found to fix ammonium, but present evidence indicates that the clay minerals chiefly responsible for ammonium fixation in soils are illite, vermiculite, and montmorillonite (Allison et al., 1951, 1953a, 1953b; Hanway and Scott, 1956; Nommik, 1957; Schreven, 1963, 1968). These clay minerals are described as aluminosilicates of the three-layer type, with lattice layers composed of two silica tetrahedral sheets and a central alumina octahedral sheet (Jackson, 1964; Grim, 1968). The layers are continuous in the a and b directions and are stacked one above the other in the c direction. Two common characteristics of these clay minerals are expansible interlattice spacings along the c direction and isomorphous substitutions within the clay lattices. The latter have resulted in charge deficiencies on the outside surfaces of the clay mineral structure, and these deficiencies are balanced by cations which occur chiefly between the lattice layers.

In an essentially unweathered mica these charge deficiencies are balanced by interlayer potassium (Jackson, 1952). In clay minerals such as illite, vermiculite, or montmorillonite this interlayer potassium has been partly or wholly replaced by other cations which are largely exchangeable. Thus, in illite the interlayer potassium may be partially replaced by  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ , and  $\text{Na}^+$ , while the balancing cation for vermiculite is predominately  $\text{Mg}^{++}$ , and for montmorillonite  $\text{Ca}^{++}$ ,  $\text{Na}^+$ , and  $\text{H}^+$  (Nommik, 1965; Grim, 1968).

X-ray diffraction studies have shown that under conditions of cation exchange the ammonium ion replaces interlayer cations such as



$\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ , and  $\text{Na}^{+}$  in the expanded lattice of clay minerals. This replacement causes contraction of the lattice spacing and entrapment of the ammonium between interlayer surfaces (Barshad, 1948, 1950, 1954a, 1954b). Similar observations of lattice contractions have been made in studies on potassium fixation, and on the basis of the definite relationship shown to exist between the fixation of potassium and ammonium, these cations are thought to be fixed by the same mechanism (Stanford and Pierre, 1946; Joffe and Levine, 1947).

A more specific mechanism of fixation of the potassium and ammonium ions was proposed by Page and Baver (1939). It had been generally accepted that the exposed interlattice surfaces of expanding lattice type minerals consisted of a layer of oxygen ions arranged hexagonally, the voids at the center of each hexagon having a diameter of 2.8 Å. Cations such as potassium and ammonium with ionic radii of 1.33 and 1.48 Å, respectively, would fit closely into the spherical spaces of adjacent oxygen surfaces which would result in strong bonding between lattice layers and would cause the interlayer spacing to contract. Cations with larger radii would remain more loosely held because they cannot enter into the hexagonal voids; and smaller cations, although capable of entering the voids, would be too small to contract and bind adjacent lattice layers. Experimental results reported by Page and Baver (1939) and many others (e.g. Barshad, 1948) lend strong support to this theory which is still regarded as the principal mechanism of ammonium fixation (Nommik, 1965). A number of diagrams of vertical and horizontal sections of interlattice surfaces have been presented to illustrate this mechanism of fixation (Mela Mela, 1962; Jackson, 1964; Nommik, 1965). In addition to the importance of ionic



radii in cation fixation by lattice clay minerals, Young and McNeal (1964) proposed that bonding mechanisms of hydrogens of the ammonium ion could also be operative to provide greater attraction for stabilizing the ammonium ion in the interlattice voids.

### C. Factors affecting fixation

Many investigations into the phenomenon of ammonium fixation have been carried out with the use of relatively pure clay materials. It has been shown that ammonium fixation by vermiculite is extensive, that montmorillonite fixes appreciable amounts only after drying, and that fixation by illite is greatly affected by the degree of weathering of this mineral (Barshad, 1948, 1954b; Allison et al., 1953c; Allison and Roller, 1955b; Young and McNeal, 1964). These clay minerals, then, could be expected to greatly affect the fixation properties of soils. Allison et al. (1951, 1953, 1953b) reported appreciable fixation of ammonium in soils having predominantly illite or vermiculite in the clay fraction, while soils containing mainly montmorillonite had low fixation under moist conditions and only moderate fixation after the soil had been allowed to air dry.

Further, the stage of weathering of clay minerals, particularly the extent of depletion of interlayer potassium in illite, has been noted for its influence on the ammonium fixation properties of soils. Schreven (1963, 1968) found little ammonium fixation in young polder soils containing illite with high levels of potassium and essentially closed lattices, but was able to measure considerable fixation in old marine clay soils in which the illite had been depleted





of some of its interlattice potassium.

While the per cent clay content of soils is generally regarded as an important factor in ammonium fixation, positive correlations between increased fixation and increasing clay content have not been very close even in surveys involving large numbers of samples (Nommik, 1957). Rich and Lutz (1965) reported from their survey that the coarse clay fraction was generally the most important with respect to ammonium fixation which is in agreement with observations that low fixing montmorillonite tends to accumulate in the fine clay fraction. Nommik (1957, 1965) reported ammonium fixation by the silt fraction, which suggests that this fraction may also contribute to the fixation properties of a soil. Therefore, no general correlation can be expected between the clay content and the ability of a soil to fix ammonium. Some workers have attributed variations in the amounts of ammonium fixed to differences in the mineralogical composition of the clay fraction (Nommik, 1957; Mela Mela, 1962; Schiller and Walicord, 1964).

The rate of the fixation reaction involving the ammonium ion is believed to be fairly rapid. Data on the initial rate of fixation are somewhat at variance. Nommik (1957) measured that 62 per cent of the total fixation had occurred within the first 10 minutes, while Schreven (1968) found fixation to be 75 per cent complete after the first 5 minutes. Other experimental results indicate that most fixation reactions in soils and clay minerals have reached equilibrium after 48 to 72 hours of reaction time (Keay and Wild, 1961; Newman and Oliver, 1966; Schreven, 1968). Jansson (1958) reported complete fixation after 24 hours in one experiment but found increases of 3 to 8 per cent in another experiment in which contact had been allowed to continue from





3 to 17 days. Nommik (1957) also observed fractional increases in fixation after prolonged periods of reaction. Newman and Oliver (1966) demonstrated with tracer methods that under extended conditions of fixation the replacement of interlayer ions by ammonium was continuing, though very slowly.

The foregoing and numerous other experiments were conducted under conditions of moist fixation which generally yielded rather low values for fixed ammonium, and only a few investigators have reported appreciable fixation under moist conditions (Bower, 1950; Allison et al., 1951; Hanway and Scott, 1956; Nommik, 1957). Drying the soil after the addition of ammonium salt solutions has resulted in substantially higher fixation of ammonium. Allison et al. (1951, 1953b) found that fixation increased two to threefold after air drying and up to sixfold after oven drying. Similar trends have been observed by other workers (Bower, 1950; Nommik, 1957; Stojanovia and Broadbent, 1960; Young, 1964). Dehydration of the interlayer spacing and the increasing concentration of ammonium in the soil solution through the removal of water on drying are regarded as being responsible for the increase in fixation (Nommik, 1965).

The treatment of soils with increasing amounts of ammonium has generally resulted in an increase in the total amount of ammonium fixed but a decrease in the percentage fixed (Nommik, 1965). This trend has been observed over widely differing ranges of application. On the basis of ammonium nitrogen added per 100 g of soil, the lower applications ranged from 0.2 to 1.4 me (Jansson, 1958) and the higher applications up to 40 me (Nommik, 1957; Mela Mela, 1962). In other investigations, however, the amounts applied did not exceed 20 me, and



results generally have shown that the capacity of soils to fix added ammonium was virtually satisfied at rates between 5 and 10 me of added ammonium nitrogen per 100 g of soil (Bower, 1950; Allison et al., 1951; Nommik, 1957; Schiller and Walicord, 1964).

The content of organic matter and the level of potassium in the soil have also been noted as factors affecting the fixation of ammonium. Many observations are in agreement that the capacity to fix added ammonium is greater in subsoils than in the corresponding surface soil (Bower, 1950; Hanway and Scott, 1956; Legg and Allison, 1959; Peterburgsky and Smirnov, 1966). This difference in fixation may in part arise from organo-clay complexes and particles of organic matter either preventing the collapse of the lattice spacing or blocking the entry of ammonium ions to the fixing sites. Hinman (1966) reported that the amount of ammonium fixed increased up to 45 per cent on destroying the organic matter prior to the addition of ammonium, and that this increase was greater the higher the organic matter content of the sample. Thus, the organic matter appears to reduce the fixation of ammonium.

The effects of potassium on the fixation of ammonium largely have been attributed to the definite relationship known to exist in the fixation of these ions. Based on an investigation of about 400 surface soils, Nommik (1957) reported decreasing ammonium fixation with increasing levels of exchangeable potassium. Conversely, Acquaye and MacLean (1966) noted that the fixation of potassium was repressed by the presence of ammonium. Results from a number of studies have indicated that prior application of potassium caused a proportionate reduction in the capacity of soils to fix ammonium (Bower, 1950;



Nommik, 1957; Jansson, 1958; Schiller and Walicord, 1964; Hinman, 1966). Simultaneous additions of equivalent amounts of both ions, however, did not repress ammonium fixation to the same extent but resulted in a preferential fixation of the ammonium ion (Nommik, 1957, 1965). This observation was made over a fairly wide concentration interval, the ratio of fixed ammonium to fixed potassium ranging from 2.8 to 3.4.

The cause of the higher fixability of ammonium over potassium may be sought in the small difference of the interlayer space of the contracted mineral. Ammonium saturated lattices of vermiculite have shown to be about  $0.8 \text{ \AA}$  greater than lattices saturated with potassium (Barshad, 1954b). This small expansion through the ammonium ion is believed to render the potassium ion more accessible for a replacement by ammonium than vice versa (Nommik, 1965).

#### D. Determination of ammonium fixation

Direct and indirect methods have been used for studying ammonium fixing properties of soils. The indirect method involves treatment of the soil with a known amount of an ammonium salt solution and, after prolonged contact, extraction and determination of the exchangeable ammonium. The difference between the ammonium added and that recovered represents the ammonium fixed. Treatments with small amounts of dilute ammonium salt solutions give a fairly sensitive measure of the ability of a soil to fix ammonium from light applications. Additions of excessive amounts, while designed to estimate the total capacity of a soil to fix ammonium, give a rather insensitive measure, especially in soils in which fixation of ammonium is low.





Direct methods for the determination of fixed ammonium involve the pretreatment of the soil with an ammonium salt solution and the subsequent removal of the exchangeable ammonium by leaching with KCl. The soil is then exposed to harsh chemical treatments to effect the partial or complete breakdown of the layer silicates, thereby liberating the ammonium entrapped in the interlattice spacing. The increase in the ammonium content of the treated sample over the control soil represents the quantity of ammonium fixed.

In one of the direct methods the ammonium treated soil is subjected to Kjeldahl digestion for total nitrogen analysis (Allison et al., 1951). With some modification this procedure has yielded fully reproducible results (Dhariwal and Stevenson, 1958), but for soils with high total N content and low capacity for fixation the method is rather insensitive (Nommik, 1965).

Barshad (1951) proposed an alkaline duplicate distillation procedure, in which one ammonium pretreated sample is distilled with NaOH and a duplicate sample with KOH. The fixed ammonium is estimated from the difference between the amounts of nonexchangeable ammonium released by the two distillations.

Bremner (1965) developed a method in which the sample is pretreated with a KBr-KOH solution and washed with KCl for the removal of organic N compounds and exchangeable ammonium. The residue is treated with 5 N HF - 1 N HCl to decompose minerals containing nonexchangeable ammonium, and the ammonium released by this treatment is then determined by collection and titration of the ammonium liberated on steam distillation. This method is based on the finding that pretreatment with KBr-KOH minimized the interference by organic





N compounds and that there is virtually no possibility of ammonium fixation by silicate minerals during the treatment of soils with this reagent (Bremner, 1965). Earlier, Dhariwal and Stevenson (1958) and Bremner (1959) have shown that HF treatments affect quantitative recovery of ammonium from various silicate minerals. It must be emphasized, however, that there is no way of proving that the KBr-HF method, or any other method, for estimating fixed ammonium in soils is accurate. It is possible that soils contain fixed ammonium which is not associated with silicate minerals and further, that soils may contain labile organic N compounds within the lattices of silicate minerals which are not removed by the KBr pretreatment but which are released and extensively decomposed to ammonium during the exposure of the sample to the HF-HCl reagent (Bremner, 1965).

Surface soils, with few exceptions, have been found to fix less than 1.0 me of added ammonium per 100 g of soil (Allison et al., 1953b; Nommik, 1957; Walsh and Murdock, 1960; Moore, 1965; Lutz, 1966). Natural weathering appears to exert only a mild influence on the fixation properties of soils. Schreven (1968) postulated that it may have taken several centuries for certain Dutch soils to change from an essentially non-fixing soil to one of low fixation capacity. However, accelerated leaching with water over a one-year period has been shown to substantially increase the capacity of a soil to fix added ammonium (Mela Mela, 1962), and systematic cropping and fertilization has been reported to significantly alter the fixation properties of soils under field conditions (Schiller and Walicord, 1964; Peterburgsky and Smirnov, 1966).



#### E. Biological availability of fixed ammonium

The term "fixed ammonium", defined as ammonium not extractable by 2 N KCl, does not imply anything about the biological availability of this ammonium fraction. Regarding the release of fixed ammonium, Leggett and Moodie (1962) presented data showing continuing defixation of ammonium from high fixing soils. However, the observed release was slow and the rate of release diminished as the extraction was prolonged.

Similar observations to the foregoing have been made regarding the availability of fixed ammonium to nitrifying microorganisms. In some studies the initial availability of fixed ammonium was followed by a sharp reduction or complete cessation of nitrification (Bower, 1951; Welch and Scott, 1960; Reid et al., 1969). These findings suggest that nitrifying organisms have a limited ability to utilize fixed ammonium. On the other hand, Nommik (1966) and Schreven (1968) observed gradually diminishing nitrification of fixed ammonium throughout incubation periods of 40 days.

The interference of potassium with nitrification of fixed ammonium has been reported by Welch and Scott (1960) who demonstrated that, as additions of potassium were increased, there was a corresponding decrease in nitrification of fixed ammonium. The effectiveness of potassium to block fixed ammonium from becoming available to microorganisms was also evident from results by Nommik (1966). Schreven (1968) observed that additions of potassium before or after the addition of ammonium had different effects on the blocking of fixed ammonium for nitrification. The blocking was more effective when potassium was added after the addition of ammonium. According to



Welch and Scott (1960) some of the divergent results obtained on the release of fixed ammonium to nitrifying organisms can be attributed to varying levels of exchangeable potassium in the soil and in clay minerals used. Lutz (1966) reported a very low correlation between the amounts of nitrification and fixed ammonium, but found good correlation between nitrification and organic matter content both for untreated samples as well as for samples in which ammonium had been fixed. Thus, organic matter content could also confound the results for nitrification of fixed ammonium.

The availability of fixed ammonium to agricultural crops has been investigated in a number of greenhouse experiments. Bower (1951), using a modified Neubauer technique, found that barley seedlings recovered very little fixed ammonium and that per cent recovery was almost identical for incubation and plant growth experiments. He concluded that bacteria were capable of utilizing more of the fixed ammonium and that the bacterial transformation of this ammonium was essential for the growth of barley. Allison et al. (1953a) recorded low availability of fixed ammonium to millet in the greenhouse and slightly higher availability to bacteria in incubation tests which led the authors to assume that nitrate formation could be a rather accurate measure of availability of fixed ammonium to plants. Nommik (1957) obtained high recovery of fixed ammonium by oats. Recovery of nitrate by oats was insignificantly greater so that the oat plants were considered highly effective in utilizing fixed ammonium.

Nitrate treatments for comparative purposes have also been used by Legg and Allison (1959) who found that banded ammonium was as





available to Sundangrass as was nitrate, but recorded lower uptake of nitrogen from ammonium mixed throughout the fixing soil. However, this differential uptake could not be attributed entirely to ammonium fixation because ammonium recovery from a high-fixing subsoil was nearly identical to that from a non-fixing surface soil. Axley and Legg (1960) obtained similar results in greenhouse studies with oats and corn and were likewise unable to attribute differential nitrogen uptake to ammonium fixation since the soil with the highest fixation capacity was least affected. The addition of small amounts of potassium to high fixing soils has been shown to depress the uptake of fixed ammonium by oats (Nommik, 1957), and corn and oats responded similarly in low fixing soils to which large amounts of potassium had been added (Axley and Legg, 1960). These results suggest that the amount of potassium required to reduce significantly the availability of fixed ammonium to plants depends on the ammonium fixation capacity and the initial potassium status of the soil.

Walsh and Murdock (1963) obtained highly significant correlations between exchangeable potassium in the soil after cropping and the amount of applied ammonium fixed as measured by differential nitrogen uptake by corn, which indicated that the level of potassium in the soil was a controlling factor in the release of fixed ammonium to the crop. In addition to the foregoing, different crops have been shown to vary in their effectiveness to utilize fixed ammonium. Oats and wheat have been considered highly effective, with barley, sugar beets, and potatoes taking an intermediate position, while rape and mustard appear to be the least effective crops in this respect (Nommik, 1965). However, there are several factors that control the uptake of the ammonium ion





by plants even when this ion is readily available. Aeration, pH, and ionic composition of the culture medium as well as the carbohydrate status of the plant and the plant species have been singled out as the dominant factors (Mevius, 1928; Pirschle, 1929, 1931; Naftel, 1931; Clark and Shive, 1934; Arnon, 1937; Street and Sheat, 1958). Thus, the utilization of fixed ammonium by plants would be largely influenced by factors controlling the uptake of the ion.

The information on the biological availability of fixed ammonium, although extensive, is primarily based on results obtained in laboratory and greenhouse experiments and is therefore not directly applicable to field conditions. The limited number of short-term field studies conducted thus far have shown appreciable fluctuations from one year to another and the variable and often inconsistent results obtained have not been satisfactorily explained (Nommik, 1965). Long-term field trials appear to be more promising, since systematic applications of nitrate, ammonium and potassium fertilizers have not only resulted in significant differences in crop yield and nitrogen uptake, but have also brought about measurable changes in the ammonium fixation capacities and the potassium status of the soil, consistent with the fertilizer treatments (Schiller and Walicord, 1964; Peterburgsky and Smirnov, 1966).



#### F. Summary of literature review

The following is to emphasize the areas pertinent to the current studies.

1. The concept of fixed ammonium is somewhat arbitrary and is primarily based on the method used to determine this ammonium fraction.
2. Since exchangeable ammonium is defined as ammonium extracted with 2 N KCl, fixed ammonium may be defined as ammonium not extractable with this reagent.
3. The capacity of a soil to fix ammonium is determined by additions of ammonium to satisfy that capacity and subsequent determinations of the amount of ammonium fixed.
4. It has been well established that air drying of soils under laboratory conditions increases the fixation of added ammonium. This trend may readily apply to surface layers of the soil under field conditions.
5. As potassium is known to be fixed by the same mechanism as ammonium, the potassium status of a soil or additions of potassium have been reported to influence the fixation of ammonium.
6. The availability of fixed ammonium to microorganisms has been measured by nitrification of added ammonium, with nitrate treatments used for comparison.



7. The availability of fixed ammonium to higher plants has been investigated with the use of many plant species of agricultural importance. Several species have been shown to vary in their ability to utilize fixed ammonium, but these variations must be considered along with other factors that control the uptake of ammonium ions by plants.



## MATERIALS AND METHODS

### A. Sampling areas and soils

The soil samples used in this study were surface soils collected from different areas of the province of Alberta as indicated on the map in Figure 1. A total of 101 samples were made available, of which 56 had been collected in the Peace River area during 1963 and 1964 for a study of ammonium fixing properties of soils in that area<sup>1</sup>. The remaining 45 samples were collected in 1969 from sites of various fertility projects conducted by the Department of Soil Science in the central, east central, northwest and northeast areas. In all, the available samples encompassed a range of soils in the Dark Brown, Black and Gray Wooded soil zones of Alberta. Soil subgroup, soil series and legal locations, arranged by sampling area, are given in Appendix A. The soils were sampled to a depth of 15 cm, air dried, crushed to pass a 2 mm sieve and stored in sealed plastic bags or in glass jars.

Twelve soils were selected for greenhouse and incubation studies to determine the agronomic significance of fixed ammonium. They were chosen from among the 45 soils of the fertility projects on the basis of ammonium fixing capacities as determined in the laboratory. Further, these soils represented a range of textures and organic matter content. Classification and legal locations are listed in Table 1.

Bulk samples of surface soil were collected from check plots at the field project sites in the fall of 1969, after the plots had

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<sup>1</sup> The author is indebted to Dr. M. Nyborg, Department of Soil Science, for making these samples available.





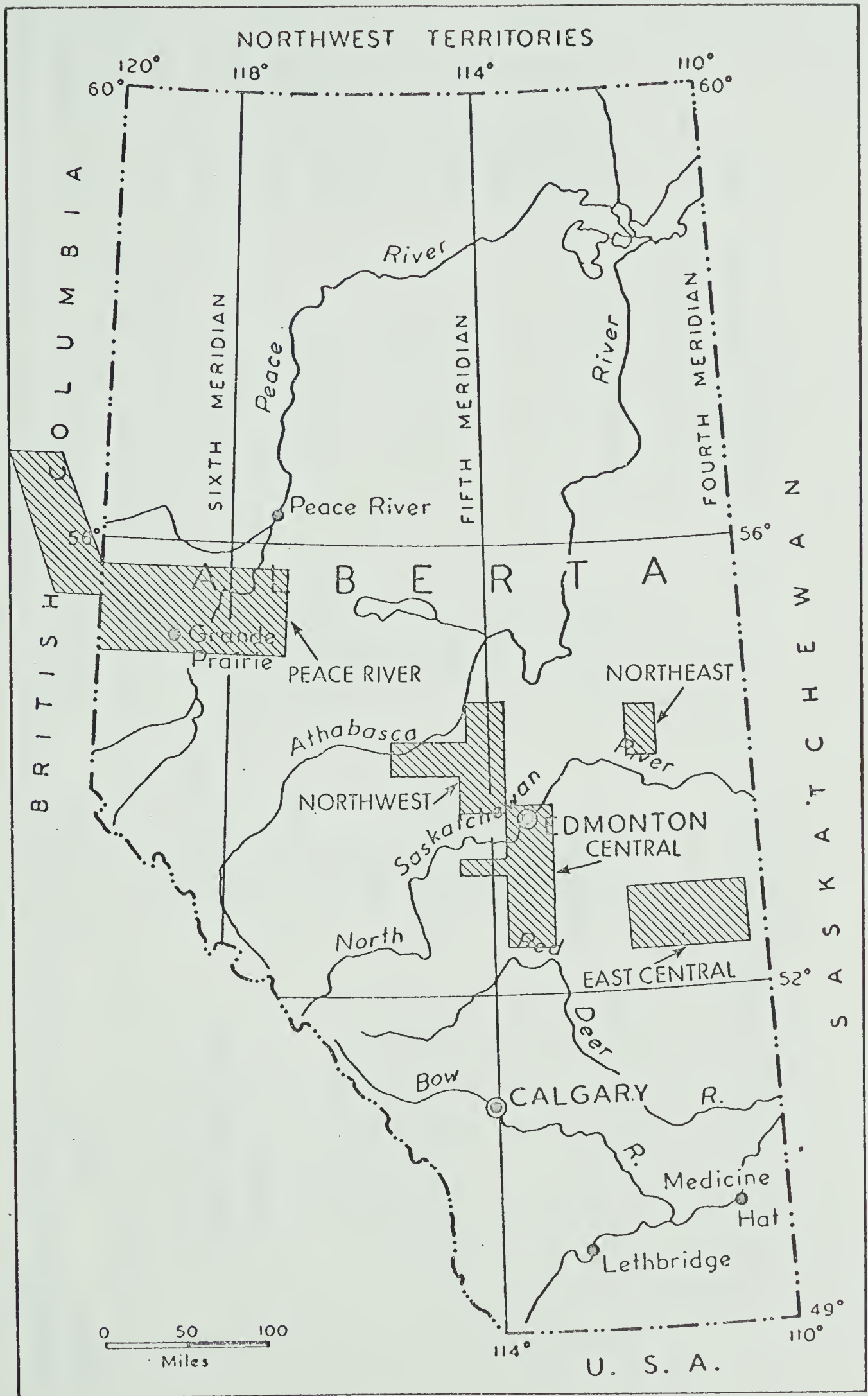


Figure 1. Location of sampling areas.



TABLE 1. Classification and legal location of soils for greenhouse and incubation experiments

Number	Subgroup	Soil series	Texture	Parent Material	Legal Location
1	Dark Gray Luvisol	Fawcett	Loam	Alluvial-Lacustrine	NW-11-64-27-4
2	Orthic Dark Brown	Hughenden <sup>a</sup>	Loam	Glacial Till	SE-27-40-12-4
3	Eluviated Black	Ponoka	Sandy Loam	Alluvial-Lacustrine	NE-24-40-27-4
4	"	Angus Ridge	Loam	Glacial Till	SE-11-54-22-4
5	Orthic Black	Malmo	Silty Clay Loam	Lacustrine	NE-24-51-25-4
6	Solodic Dark Gray	Majeau	Clay	"	NW-23-56- 3-4
7	Orthic Gray Luvisol	Cooking Lake	Loam	Glacial Till	SE-28-52-21-4
8	"	Breton	Loam	"	NW-29-41-23-4
9	"	La Corey	Sandy Loam	"	SE-13-60-13-4
10	"	Breton	Loam	"	NE-25-47- 4-5
11	"	Athabasca	Silt Loam	"	NW-30-65-14-4
12	Humic Eluviated Gleysol	Jarvie	Silty Clay	Alluvial-Lacustrine	NW-12-64- 1-5

<sup>a</sup> Probably Hughenden series; mapped as 2.32/6 in Soil Survey of Sullivan Lake Sheet, 1938, University of Alberta, Bulletin No. 31.



been harvested. The samples were spread out in a drying chamber, dried at 35° C, passed through a 5 mm sieve and stored in large plastic bags.

## B. Laboratory procedures

### Ammonium fixing capacity

A method described by Nyborg (1969) for estimating the capacity of the mineral fraction of soils to fix ammonium was used with some modification. Duplicate 1 g samples ground to pass a 0.25 mm sieve were weighed into 125 ml Erlenmeyer flasks and held in 2 ml  $\text{NH}_4\text{Cl}$  solution of 0.14% N for three days. The extraction of exchangeable ammonium was effected by adding to each flask 100 ml of 2 N KCl and by shaking the samples intermittently for an additional three days. The ammonium in the extractant was determined on 20 ml aliquots by steam distillation with MgO and titration of the distillate with 0.005 N  $\text{H}_2\text{SO}_4$  from a 5 ml microburette as outlined by Bremner (1965). The fixation capacity of the soil was calculated from the amount of added ammonium that was not extracted.

### Fixation of ammonium added at different rates

The soils used for this study were those selected for the greenhouse and incubation experiments. Several hundred grams of each soil were ground to pass a 1 mm sieve.

The method described by Nyborg (1969) for the determination of ammonium fixing capacity was further modified for this study in which ammonium was to be applied at lower rates. These modifications were in the soil:solution ratio, the drying period for part of this



work and in the following seven rates of application of ammonium-N:

35 ppm	210 ppm
70 ppm	280 ppm
105 ppm	560 ppm
140 ppm	

Fixation under moist conditions. Duplicate 5 g samples were weighed into 125 ml wide-neck Erlenmeyer flasks and held in 10 ml  $\text{NH}_4\text{Cl}$  solutions of appropriate concentrations for three days. Exchangeable ammonium was extracted by adding to each flask 100 ml of 2 N KCl followed by intermittent shaking of the samples for three days. The ammonium in the extractant was determined by steam distillation as described previously, and the added ammonium not extracted was assumed fixed.

Fixation after drying at 30° C. Duplicate 5 g samples were weighed into 125 ml wide-neck Erlenmeyer flasks and held in 5 ml of  $\text{NH}_4\text{Cl}$  solutions of appropriate concentrations for three days, after which the flasks were placed in an air-forced oven and the samples dried in the flasks at 30° C for 18 hours. The determination of exchangeable and of fixed ammonium was the same as described for the fixation under moist conditions.

#### Analysis of soils

Analysis of particle size distribution in soil samples followed the pipette method described by Toogood and Peters (1953), except carbonates were removed by the addition of hydrochloric acid.





Field capacity moisture content per cent was estimated by a method using a pressure-plate apparatus at one-third atmosphere pressure, as described in U.S.D.A. Handbook 60 (1954).

Hygroscopic moisture content per cent of soil samples was calculated from loss of weight after drying at  $105^{\circ}$  C for 24 hours.

Soil reaction (pH) was determined on the supernatant of a 0.01 M  $\text{CaCl}_2$  suspension as described by Peech (1965), using a glass electrode pH meter.

Exchangeable ammonium nitrogen and nitrate nitrogen were extracted with 2 N KCl using 100 ml of extractant for 20 g soil samples. An aliquot of extractant was analyzed by steam distillation with  $\text{MgO}$  for exchangeable ammonium and with Devarda's Alloy for nitrate nitrogen, as outlined by Bremner (1965).

Kjeldahl nitrogen determinations for organic and ammoniacal N were done according to the Official Methods of Analysis of the Association of Official Agricultural Chemists (1950).

Cation exchange capacity was determined by ammonium saturation with  $\text{NH}_4\text{Ac}$  and subsequent displacement and distillation of the ammonium as described by Chapman (1965).

Exchangeable potassium was analyzed in the  $\text{NH}_4\text{Ac}$  extract obtained from the C.E.C. determination. The analysis was performed with the use of a Perkin-Elmer Atomic Absorption Spectrophotometer.

Organic carbon content was evaluated by single sample analysis in a Leco Induction Furnace.



## Analysis of plant material

Plant material from the greenhouse experiments and the second solution culture experiment was analyzed for nitrogen content by the Standard Bremner method (Bremner, 1960), using 10 ml of concentrated  $\text{H}_2\text{SO}_4$  and 2 hours for digestion. 10 ml aliquots of diluted digest were steam distilled in a modified Markham apparatus, and 30 ml of distillate were titrated with 0.02 N  $\text{H}_2\text{SO}_4$  from a 5 ml burette as outlined by Bremner (1965).

## C. Greenhouse experiments

Three 10 kg portions (oven-dry basis) were taken from the bulk samples of each of the 12 soils selected for the greenhouse experiments. One portion was treated with 30 ppm of  $\text{NH}_4\text{-N}$ , another with  $\text{NO}_3\text{-N}$  and the third was left untreated as a check. The portions of soil to be treated were spread on plastic sheets approximately 1.5 x 2.0 m in size. 100 ml of stock solution containing 0.3% N in either the ammonium or nitrate form were diluted to a volume which when added to 10 kg of soil, would raise the moisture content to field capacity (moisture content at 1/3 atmosphere pressure). The diluted nitrogen solution was uniformly applied to the thinly spread soil from an inverted Erlenmeyer flask which had been fitted with a spray nozzle. Further mixing of the treated soil by lifting the plastic sheet from corner to corner assured that the soil was moistened throughout. The treated portions were spread again over the plastic sheet and left to dry in a walk-in drying chamber at 30° C for 24 hours.



The treated and check portions of each soil were weighed into 15 cm plastic pots with sealed drain holes. Weights by volume differed greatly between some soils so that the weight to which the pots were filled was not identical for all soils. In order to fill all pots to the same level the following weights were used (oven dry basis):

First greenhouse experiment

Soil	Weight of soil (kg/pot)
Fawcett	1.98
Hughenden	1.94
Ponoka	1.75
Angus Ridge	1.74
Malmo	1.64
Majeau	1.49

Second greenhouse experiment

Soil	Weight of soil (kg/pot)
Cooking Lake	1.90
Breton (8)	1.90
La Corey	1.90
Breton (10)	1.90
Athabasca	1.90
Jarvie	1.40

Approximately one third of the soil weighed into each pot was removed and placed temporarily into labelled paper bags. The soil remaining in each pot was moistened with distilled water and then treated with 50 ppm of each P and K from a solution containing  $\text{KH}_2\text{PO}_4$  and  $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$ . The solution was banded with a pipette on the surface of the moist soil.

The purpose of this procedure was to place the nutrients about 2 cm below the depth of seed placement, so that both P and K would be readily available to the crop to be seeded and that potassium would not interfere appreciably with the added ammonium which had been mixed throughout the soil. The soil removed earlier was returned





and the moisture content of the total soil in each pot brought to field capacity with distilled water. The pots were covered with sheets of paper and allowed to stand overnight so that the added water could diffuse throughout the soil.

Echo rape (Brassica campestris) was chosen as the indicator crop. The limited range of fixing capacities over which the experiments were conducted made it desirable to select a more nitrogen sensitive crop than the conventional barley. Further, rape has assumed an increasing proportion of the total field crop production in Alberta particularly in the last two years, which was an additional consideration in favor of rape as the indicator crop.

In each pot two seeds of rape were placed into each of eight holes made about 8 mm deep by using a cork bore of 8 mm diameter. After seeding, the holes were filled with quartz sand and the sand was wetted by carefully adding distilled water from a wash bottle. Except for daily wetting of the quartz sand the pots were left covered with sheets of paper until emergence of the rape which occurred between 60 and 72 hours after seeding.

The experimental lay-out was a split plot design replicated four times. In each of the two experiments the six soils were assigned to the main plots, the treatments to the subplots. The experiments were located in a greenhouse compartment and were conducted during the months of January through mid-April. Illumination from banks of fluorescent lamps increased the light hours to 16 hours per day, with light-off time from 2300 hours until 0700 hours of the following day. The temperature controls were set at 20<sup>0</sup> C during day time hours, and at 15<sup>0</sup> C during night hours. However, the temperature control was not



good, especially during March and April, and day time temperature fluctuations of up to  $12^{\circ}$  C above the set value were observed.

Within ten days after seeding the number of rape plants in each pot was reduced to six for all pots in the experiment. Until the plants were well established, the soil moisture content was maintained at field capacity by adding distilled water every second day. Thereafter the soil moisture content was allowed to drop to about 60% of field capacity before being adjusted to the initial level. This process was repeated several times during the experiment and was intended to reduce the defixation of ammonium ions which might occur when a high soil moisture content is maintained.

The plants were harvested at the early flowering stage which was 35 days after seeding. They were clipped at soil level, placed in paper bags and dried at  $65^{\circ}$  F for 24 hours. The dried material was weighed to determine dry matter yield, ground to a size of 0.3 mm in a Wiley laboratory grinder and stored in plastic vials until analysis for nitrogen content.

#### D. Incubation experiments

Three incubation experiments were conducted. For the first and second, two 500 g portions of each of the 12 selected soils were treated with ammonium and nitrate nitrogen as described for the soils of the greenhouse experiments with the exception that the ammonium and nitrate stock solutions contained 0.1% N and that N was applied at the rate of 50 ppm.



For the third incubation experiment involving four of the 12 soils, three 500 g portions were treated first with 50 ppm of potassium. After drying, two of these portions were treated further with 50 ppm of nitrogen, one portion with ammonium, the other with nitrate nitrogen. For all incubation experiments treated soils and check soils were ground to pass a 1 mm sieve.

Twenty g of the prepared soils were weighed into 125 ml wide-neck Erlenmeyer flasks and moistened to field capacity by adding distilled water to a predetermined weight. Each flask was covered with a 5 x 5 cm piece of parafilm with an 8 mm central hole which provided aeration. The flasks were placed in an incubation chamber in which a constant temperature of 25<sup>0</sup> C was maintained throughout the duration of the experiment.

The experimental lay-out was a split-plot design, replicated four times, analogous to the greenhouse experiments. The moisture content of the soils was adjusted to the field capacity level at intervals of nine days. At the end of each interval the moisture content had dropped to less than 40% of field capacity. This procedure was adopted to allow for maximum ammonium fixation throughout the incubation period. After 35 days the soil in each flask was analyzed for content of nitrate and exchangeable ammonium.

#### E. Solution culture experiments

Two solution culture experiments were conducted. The experimental unit consisted of a plastic pail of eleven liter capacity with a 0.7 x 28 x 28 cm hardboard cover. The cover





contained 14 holes 1.4 cm in diameter for holding one plant per hole and a smaller central hole for an aeration tube. The nutrient solutions used in both experiments are given in Appendix G.

In the first experiment ten-day old seedlings of Echo rape (Brassica campestris) and Victory oats (Avena sativa) were "planted" into the holes of the covers by first placing cotton batten around the lower part of the stem and then inserting the plant into the hole. The cotton batten aided in holding the plants in position so that the roots were immersed in the culture solution which reached to about one centimeter below the cover.

The solution was prepared to contain 50 ppm with respect to P. Nitrogen in the ammonium and nitrate form was added at 84 ppm. The initially very acidic solution was adjusted to pH 6 in all pails, and this pH was maintained throughout the experiment by recording the pH every second day and adjusting it with additions of dilute NaOH or HCl as required. Aeration of the solutions was provided through 30 cm long glass tubes fitted at one end with a perforated glass bulb. The tubes were placed through the central holes in the covers and connected to a source of compressed air. The glass bulbs rested on the bottom of the pails, so that the air escaping through the perforation would assure gentle agitation of the solution and also serve as a source of oxygen. Both crops were replicated three times for each source of N. The experiment was located in a greenhouse compartment and was illuminated from a bank of fluorescent lamps for 16 hours per day. The plants were allowed to grow for 28 days. Roots and tops from each pail were harvested separately and dried at 65<sup>0</sup> C for determination of dry matter yield.





The second solution culture experiment was identical to the first one with the exceptions that rape was used as the only crop and nitrogen was supplied at the following rates:

3.5 ppm	for a total of	38.5 mg N
7.0 ppm	" " " "	77 mg N
14.0 ppm	" " " "	154 mg N

Each rate of application was replicated twice for each source of nitrogen, and the plants were again allowed to grow for 28 days. The harvested material was dried and weighed to determine dry matter yield and subsequently ground to a size of 0.3 mm for nitrogen analysis.



## RESULTS AND DISCUSSION

### A. Ammonium fixing capacities

Surface samples of the soils selected for this study were analyzed for ammonium fixing capacity to establish an inventory of ammonium fixing properties of a wide range of soils and to observe any trends of this property applicable to these soils.

The capacity of these soils to fix added ammonium was restricted to a range from practically no fixation to near 100 ppm with only two soils exceeding this latter value. This finding is in agreement with the observation of other workers in that surface soils generally fix less than 140 ppm of added ammonium (Allison, et al., 1953b; Nommik, 1957; Walsh and Murdock, 1960; Schreven, 1963). The ammonium fixing capacities for the individual soils are given in Appendix A.

Ammonium fixing capacities as found in the present study are relatively low when compared to fixing capacities of 400 ppm reported for a few soils (Hanway and Scott, 1956; Nommik, 1957). However, such soils appear to be rare, and in the present study only one soil was found to fix 260 ppm of added ammonium.

Within the range up to 100 ppm, 70% of the soils analyzed fixed less than 40 ppm. Generally, soils of light texture were found to fix less of the ammonium added than soils of heavy texture. To test this apparent trend the correlation of ammonium fixing capacities with per cent clay content was computed for 16 soils for which the particle size distribution had been determined. The extent to which the fixing capacities were associated with clay content was 66% for 8 Chernozemic soils but only 15% for 8 Luvisolic soils. Further, many soils with



similar clay content were found to have widely differing fixing capacities so that the per cent clay content could not be considered a good indicator of ammonium fixing capacities of soils.

Frequency distributions of fixing capacities are shown in Figure 2. They are grouped according to classification at the soil order level which places all but two of the soils about evenly into three soil orders, 31 soils into the Chernozemic Order, 36 into the Solod Great Group of the Solonetzic Order and 32 into the Luvisolic Order. The two remaining soils are of the Gleysolic Order and have widely differing capacities to fix added ammonium.

For all three soil orders the frequency distribution of fixing capacities is skewed to the region of lower fixation values. This skewness is particularly evident for the Solonetzic and the Luvisolic Orders and is less pronounced for the Chernozemic Order. The distribution patterns show further that Chernozemic soils, while high in organic matter content, have a greater tendency to fix larger amounts of added ammonium than Luvisolic soils which are generally low in organic matter content. This observation does not refute the finding by Hinman (1966) that organic matter represses the capacity of soils to fix ammonium. Rather, it can be explained by the generally low clay content in surface horizons of Luvisolic soils. The capacity of a few Luvisolic soils to fix somewhat larger amounts of added ammonium may be attributed to small portions of high fixing clay and to the fine silt fraction which is known to have some ability to fix added ammonium.

A number of samples from the Peace River area had been collected to evaluate the ammonium fixing capacity of soils of different



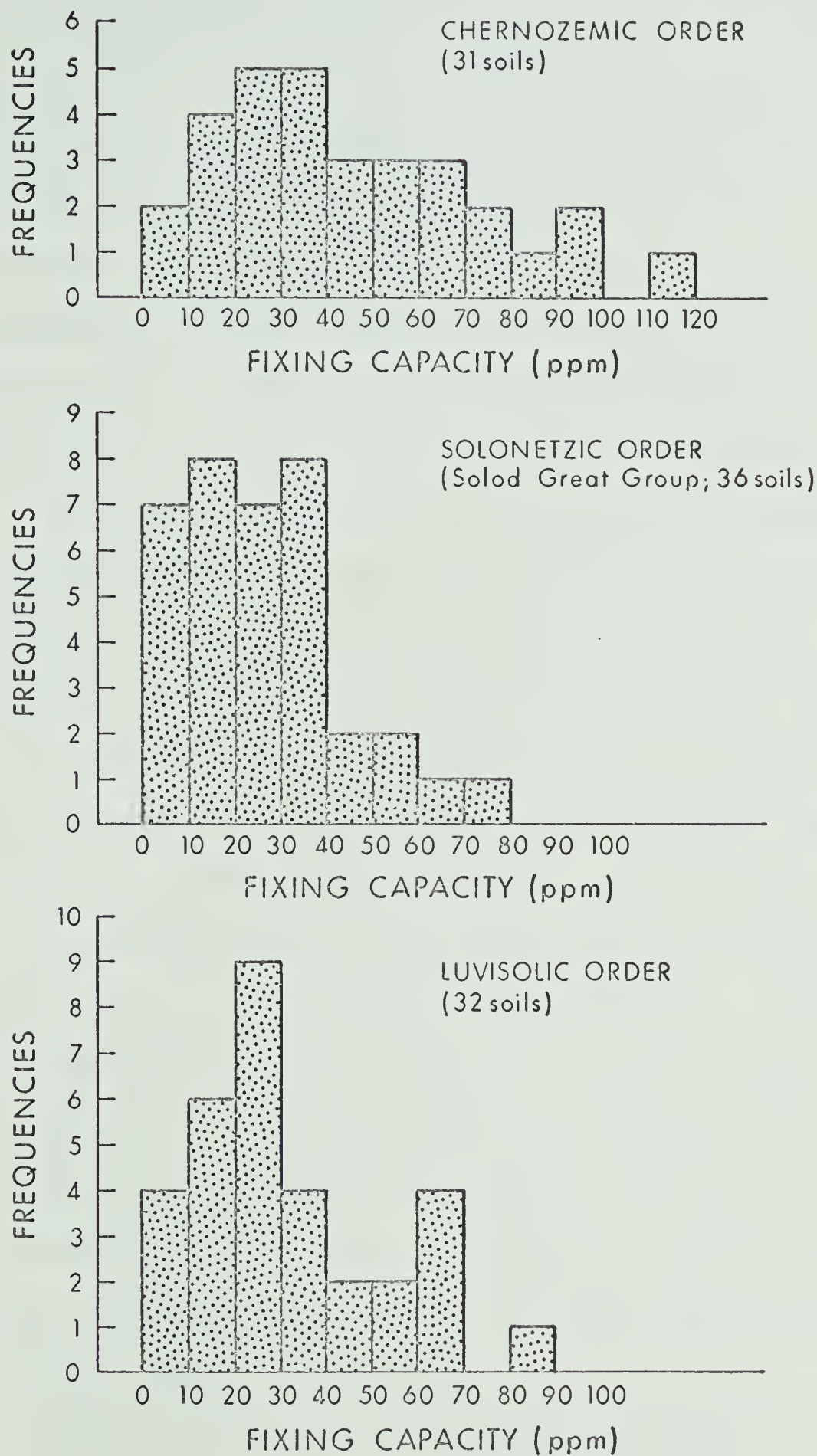


Figure 2. Frequency distribution of ammonium fixing capacities of 99 surface soils grouped by Soil Order.





series occurring in pairs in close proximity in the field. The sample group consisted of 12 samples from Landry series and three samples from each of Valleyview, Peoria, Sexsmith and Rycroft series, thus making up 12 sample pairs with Landry series represented in each pair together with one of the other series. While such sample pairs were taken from widely separated locations, sampling sites for each pair were within a distance of 300 m. Legal locations of sampling sites, grouping of series and ammonium fixing capacities are presented in Table 2.

The fixation values obtained demonstrate the variability of ammonium fixing properties within a soil series. This is particularly evident in the Landry series which is represented by 12 samples, but it is also shown by the three fixation values for each of the other four series. The limited number of observations for these series indicate, however, that soils of the Sexsmith and Peoria series fix larger amounts of added ammonium than soils of the Valleyview and Rycroft series. Considerable variability is shown also within sample pairs although for some pairs the fixation values are similar. Sample pairs B, D and G demonstrate the variability of fixing properties of soils within a small area. These sample pairs were collected from the same legal location and they encompass the range of fixation values recorded for all 24 samples of this group. If ammonium fixation is of practical significance considerable variation of its effects may be experienced within a single field of a given crop.

The observations made in this study support the view of Axley and Legg (1960) that a substantial number of locations should be sampled before any attempt is made to characterize a soil series with respect to its ammonium fixing capacity. However, the textural class of a soil



TABLE 2. Ammonium fixing capacities of Landry series and an adjacent series for 12 different locations

Legal location	Landry series	Ammonium fixing capacity ppm	Adjacent series	Ammonium fixing capacity ppm
NW-23-70-22-5	Landry A	7	Valleyview A	10
NW-15-80- 8-6	" B	7	" B	32
SE-26-72- 5-6	" C	7	" C	11
NW-15-80- 8-6	" D	13	Peoria D	11
SE- 9-71- 8-6	" E	68	" E	55
NW- 9-78-15-6	" F	32	" F	39
NW-15-80- 8-6	" G	36	Sexsmith G	77
SW-31-73- 6-6	" H	25	" H	36
SW-16-73- 6-6	" I	45	" I	50
SE-30-70-22-5	" J	18	Rycroft J	14
NW-12-73- 8-6	" K	20	" K	10
SW-35-77- 3-6	" L	17	" L	8



may have a strongly modifying influence on its fixation property so that less variability of this property may be experienced at the soil type level than has been shown to prevail at the series level.

#### B. Fixation of ammonium added at different rates

The studies to be conducted on 12 selected soils included the determination of fixation of ammonium when added at different rates. Classification and analysis of these soils are listed in Tables 1 and 4, respectively. Seven rates were chosen ranging from 35 to 560 ppm so that the study would furnish information on the extent of fixation at rates of application normally used for crop production under field conditions and extending up to rates that could satisfy the fixing capacity of these soils. Fixation of added ammonium was studied under moist conditions and after drying at 30° C and fixation data for both conditions are given in Table 3. In addition, graphs are presented in Figures 3 to 6 to show the fixation levels and trends for each soil over the lower rates of application. Figures 3 and 5 depict the soils used in the first greenhouse and incubation experiments; Figures 4 and 6 those of the second greenhouse and incubation experiments. The Jarvie soil is not shown on the graphs of Figures 4 and 6 because the high fixation values recorded for this soil are beyond the scale used for the graphs.

Figures 3 and 4 show fixation under moist conditions of ammonium added at 35, 70, 105 and 140 ppm. For all soils there is additional fixation from increased applications, and appreciable differences between some soils can be noted. Several soils show similar trends in fixation so that they may be grouped together. Thus, the





TABLE 3. Ammonium fixed in 12 surface soils<sup>a</sup> at different rates of application and two conditions of fixation

		Ammonium-nitrogen applied ppm						Ammonium fixing capacity ppm	
		35	70	105	140	210	280		560
Ammonium fixed under moist conditions (ppm) <sup>b</sup>									
1	Fawcett	0	1	3	4	5	6	7	7
2	Hughenden	2	3	5	6	7	9	15	20
3	Ponoka	2	4	6	6	8	10	22	25
4	Angus Ridge	3	7	10	14	19	24	32	48
5	Malmo	4	11	15	21	30	34	50	80
6	Majeau	3	9	17	20	35	45	54	112
7	Cooking Lake	4	6	8	10	13	18	18	18
8	Breton	3	7	11	12	14	18	20	22
9	La Corey	3	6	7	7	10	13	15	25
10	Breton	4	7	9	11	19	22	24	50
11	Athabasca	5	9	13	16	23	26	43	63
12	Jarvie	22	41	55	73	107	127	179	260
Ammonium fixed after drying at 30° C (ppm) <sup>b</sup>									
1	Fawcett	10	19	26	30	32	47	81	7
2	Hughenden	2	3	10	14	19	24	55	20
3	Ponoka	2	8	12	14	19	20	35	25
4	Angus Ridge	10	20	31	40	59	62	97	48
5	Malmo	12	28	42	55	82	98	144	80
6	Majeau	12	24	35	51	73	92	177	112
7	Cooking Lake	5	21	36	38	44	52	90	18
8	Breton	10	24	34	44	53	60	84	22
9	La Corey	11	20	26	27	38	43	80	25
10	Breton	10	22	33	46	72	89	139	50
11	Athabasca	17	32	47	61	80	94	133	63
12	Jarvie	27	56	82	112	166	217	389	260

<sup>a</sup> Surface soils used for greenhouse and incubation experiments; classification in Table 1 (p.22)

<sup>b</sup> Average of duplicates



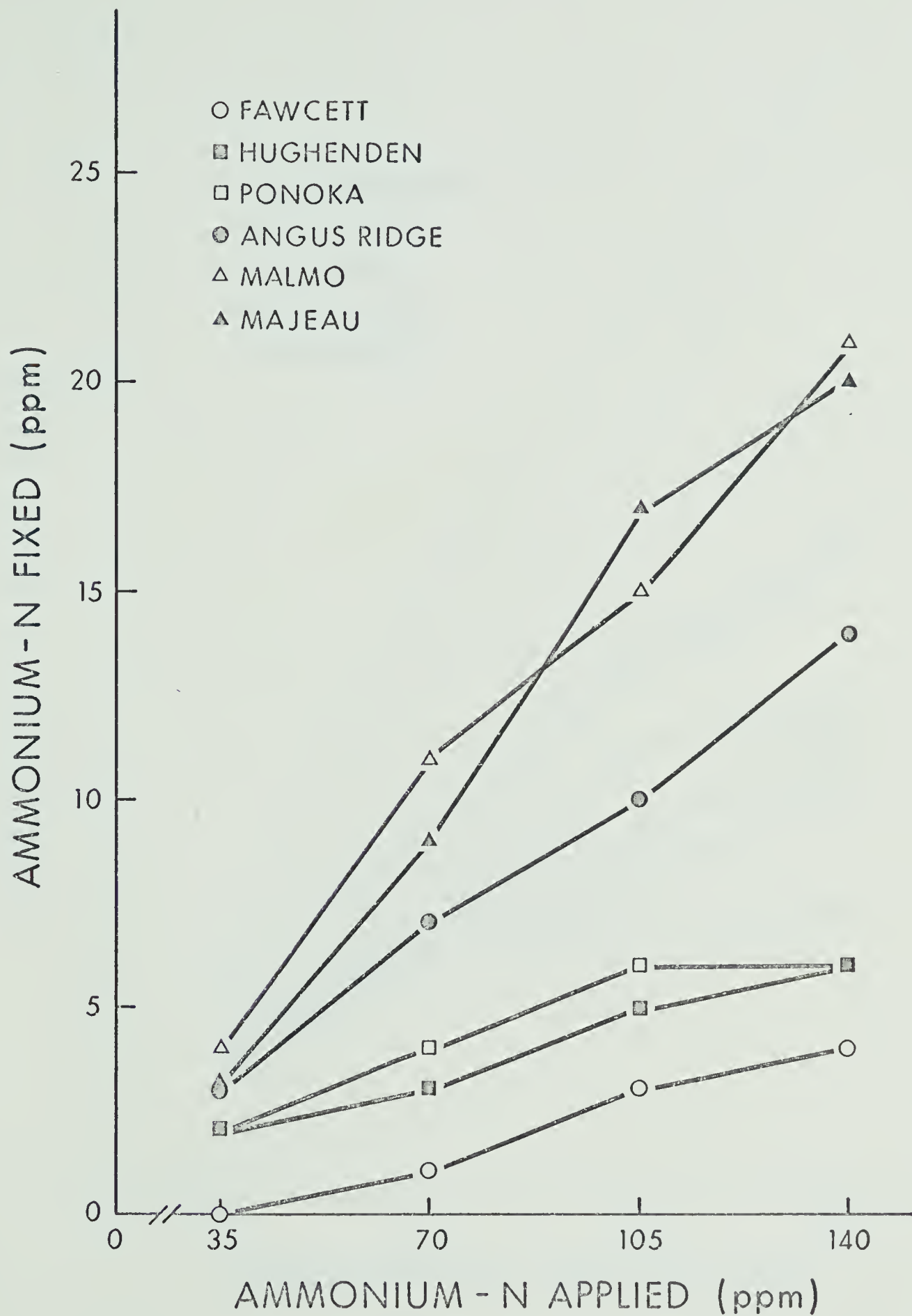


Figure 3. Ammonium fixed in 6 surface soils at low rates of application under moist conditions (Soils 1 to 6, Table 3).



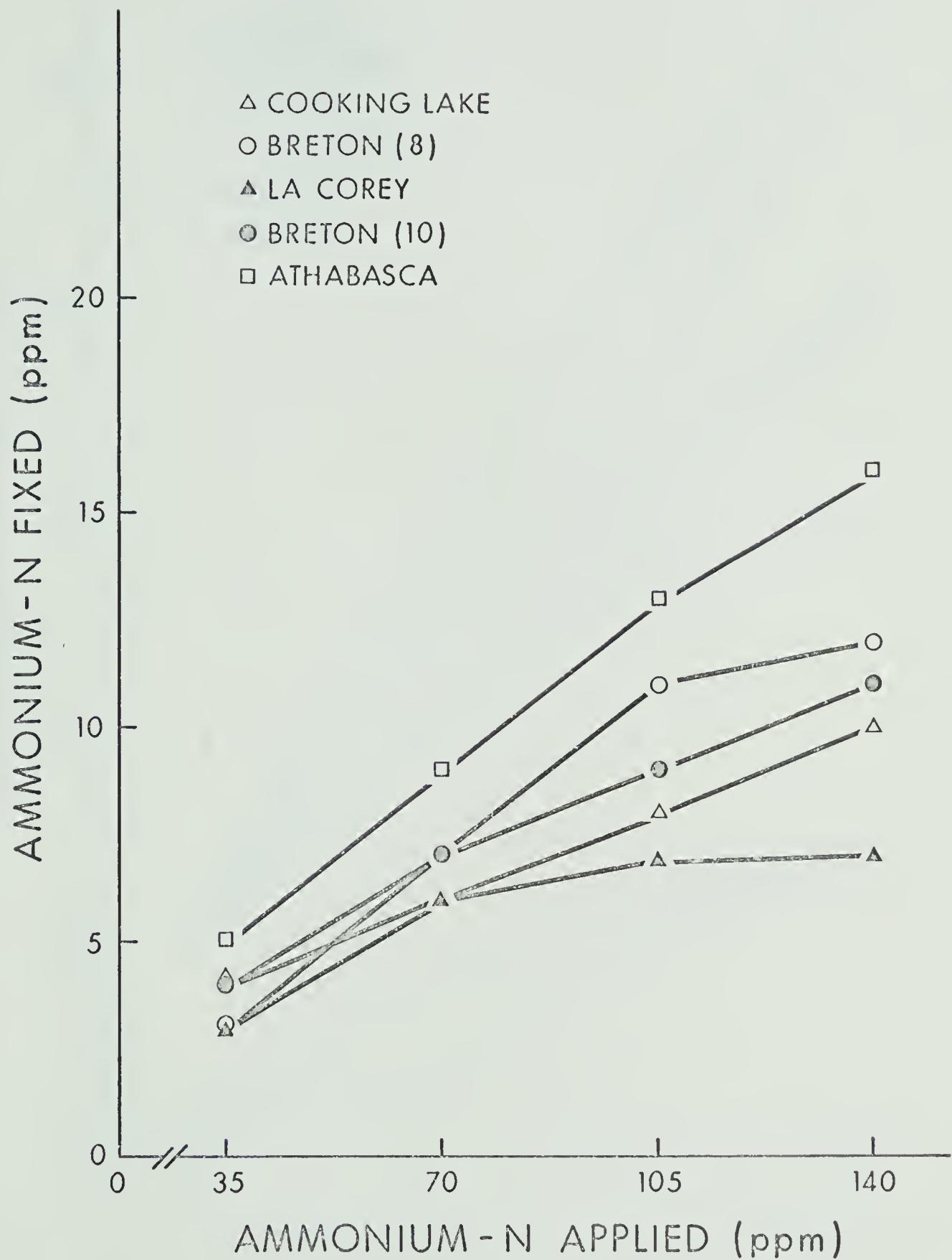


Figure 4. Ammonium fixed in 5 surface soils at low rates of application under moist conditions (Soils 7 to 11, Table 3).



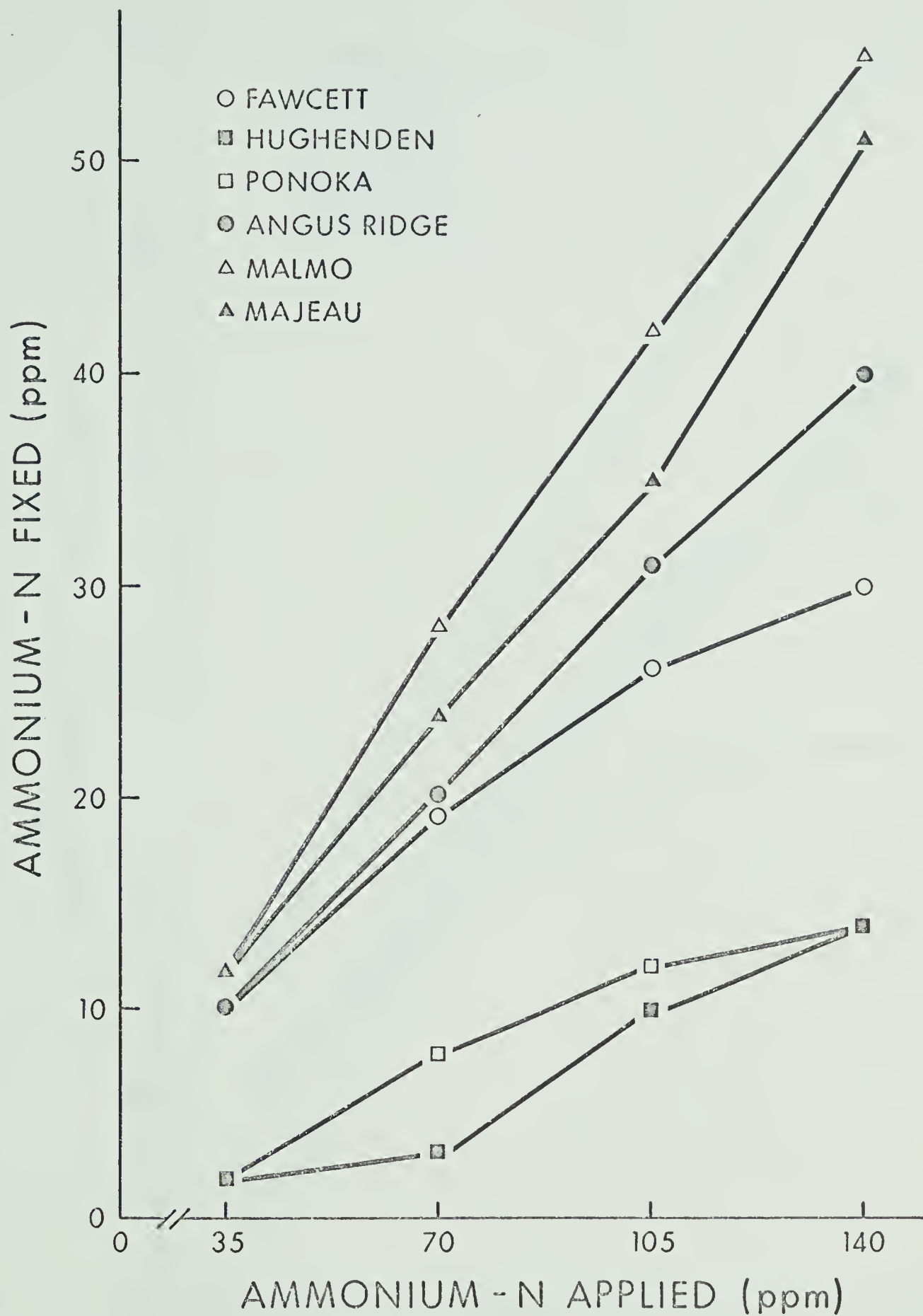


Figure 5. Ammonium fixed in 6 surface soils at low rates of application after drying at 30° C (Soils 1 to 6, Table 3).





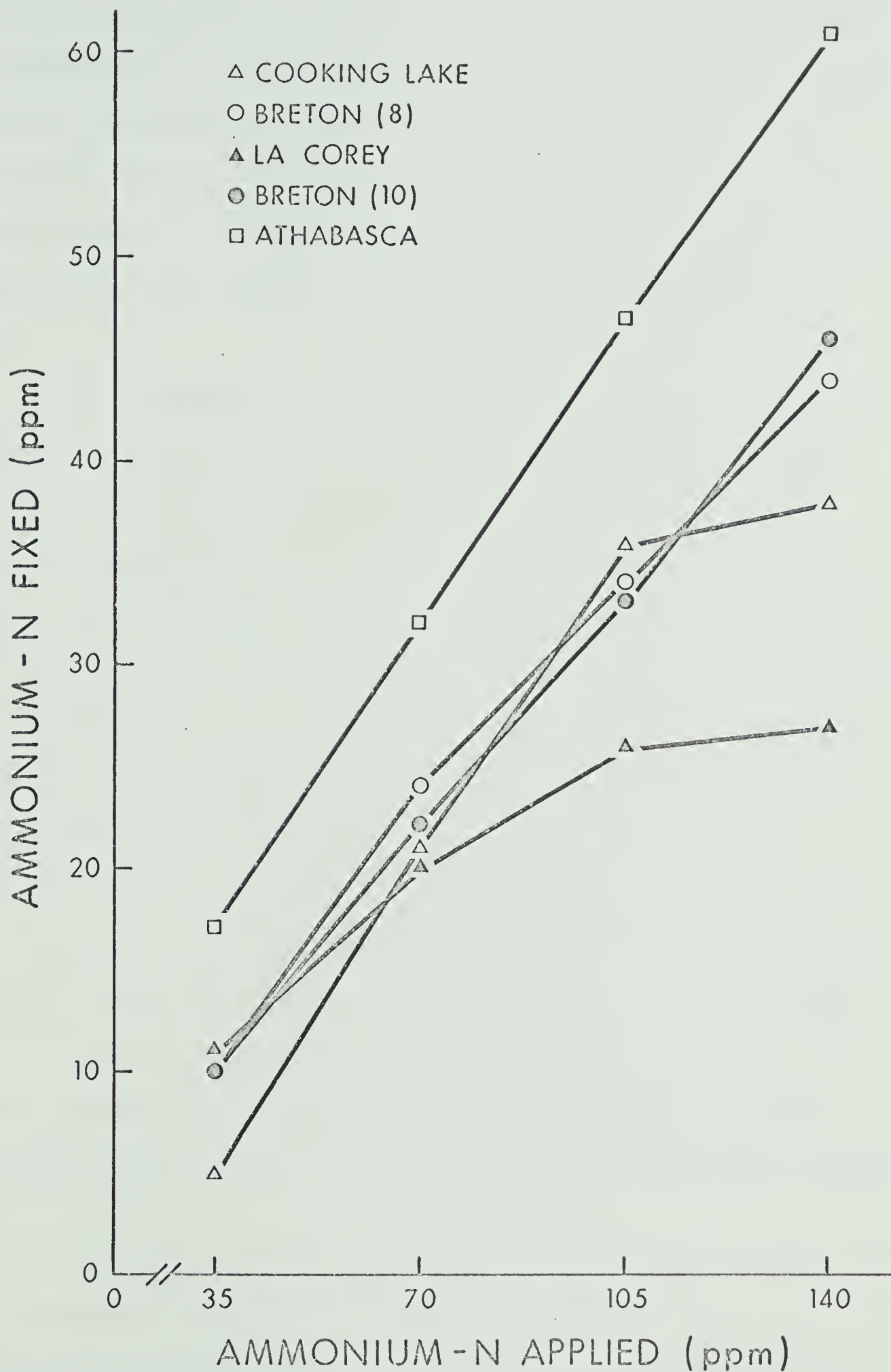


Figure 6. Ammonium fixed in 5 surface soils at low rates of application after drying at 30° C (Soils 7 to 11, Table 3).



Malmo and Majeau soils as a group have a common trend to fix larger amounts of ammonium than the Fawcett, Hughenden, Ponoka and La Corey group. The remaining soils take an intermediate position. It is worth noting that the rank order of fixation for these soils remains unchanged for the 210 to 1400 ppm range of added ammonium the values of which are shown in Table 3. La Corey is an exception to this trend.

At applications below 210 ppm fixation trends tend to converge. Several soils fix virtually the same amount of ammonium when added at 35 ppm, and determinations from additions at still lower rates would likely have confirmed a continuation of this trend. However, the methods employed in this study did not have sufficient precision to measure fixation of ammonium added at rates below 35 ppm. Thus, any inference from this study as to the practical significance of ammonium fixation must be made from the fixation values recorded for the 35 ppm rate of application. This rate is equivalent to 60 kg N/ha<sup>1</sup> which is well above average rates under present agricultural practices. Fertilizer rates currently recommend for application on stubble range from 34 to 68 kg N/ha for a number of crops including rape<sup>2</sup> and are appreciably lower for application on fallow. It can be expected that the quantity of ammonium fixed from average recommended rates for nitrogen will be lower still than those recorded

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<sup>1</sup> For depth of 15 cm and bulk density of 1.15.

<sup>2</sup> Fertilizer Guide for northern and central Alberta, 1971.  
Alberta Department of Agriculture.



for the 35 ppm rate. However, as shown in Table 3 and Figures 3 and 4, the proportion of added ammonium fixed increased as the rate of addition was decreased. For soils 2 to 11 (Table 3), fixation under moist conditions ranged from 6 - 14% of the ammonium added at 35 ppm, and this percentage would likely have been shown to increase if fixation from additions below 35 ppm had been determined. Thus, the fixation of ammonium from fertilizer applications may be of practical significance even for soils of relatively low fixing capacities. It may be of considerable significance for soils of relatively high fixing capacity as recorded for the Jarvie soil (Table 3) which has a fixing capacity of 260 ppm and under moist conditions fixed 63% of the ammonium added at 35 ppm.

Figures 5 and 6 show fixation of added ammonium after drying of the treated soils at 30° C. For all soils there was additional fixation from increased applications, but this trend was much more accentuated than for fixation under moist conditions. The eleven soils dried took much the same rank order as for moist fixations with the exception of Fawcett soil which fixed considerable amounts after drying but was lowest in fixation under moist conditions. The average increase in fixation after drying over moist fixation was threefold for the eleven soils at the four lower rates shown in Figures 3 to 6. This increase is somewhat higher than that reported by Young (1964) for the same conditions.

The increases recorded for fixation after drying may be of practical significance because it is not uncommon that soils in the sampling areas and on the Prairies be subjected to drought conditions.





The fixation data suggest that drought conditions in the field enhance fixation of applied ammonium rendering it difficultly available to crops and soil microorganisms.

### C. Greenhouse experiments

Two greenhouse experiments were conducted in 1970, one during January and February and the other from early March to mid-April. Each experiment consisted of a group of six soils fertilized with ammonium and nitrate nitrogen and seeded to rape as the indicator crop. Data of analyses on these soils are presented in Table 4.

The objective of the experiments was to relate crop yields of dry matter and uptake of nitrogen from applications of ammonium and nitrate nitrogen to the ammonium fixing properties of the soils. Chernozemic soils were selected for the first experiment because they represented ammonium fixing capacities up to 112 ppm. The Luvisolic Fawcett soil was assigned to this group so that a soil of very low fixing capacity would be included. Thus, the first group of soils encompassed all but the highest capacity (260 ppm) observed in this study. The group of soils for the second experiment was comprised of five Luvisolic soils of low organic matter content. They had a range of fixing capacities from 18 to 63 ppm, which is about one half of that in the group of Chernozemic soils. The Gleysolic Jarvie soil was included in this group so that the effect of a high fixing soil on the growth of rape could be determined.

In both experiments one portion of each soil was fertilized with ammonium chloride to allow fixation of added ammonium in which



TABLE 4. ANALYSES OF SOILS FOR GREENHOUSE AND INCUBATION EXPERIMENTS

Number	Soil series	pH <sup>a</sup>	distribution %		Organic carbon %	C.E.C. me/100g	Kjeldahl N %	Exch. NH <sub>4</sub> <sup>+</sup> ppm	NO <sub>3</sub> <sup>-</sup> ppm	Exch. K ppm	Ammonium fixing capacity ppm
			sand	silt							
1	Fawcett	6.5	48	43	9	14.9	0.18	1	3	185	7
2	Hughenden	5.3	34	41	25	26.4	0.32	3	24	650	20
3	Ponoka	5.5	54	27	19	32.2	0.49	3	5	275	25
4	Angus Ridge	6.2	33	39	28	39.4	0.48	3	2	225	48
5	Malmo	5.5	19	49	32	42.4	0.54	5	4	175	80
6	MaJean	5.6	1	37	62	45.2	0.38	8	13	775	112
7	Cooking Lake	5.6	37	43	20	11.6	0.13	2	12	120	18
8	Breton	6.1	39	49	12	13.4	0.13	1	3	128	22
9	Ia Corey	6.3	43	48	9	11.7	0.15	1	3	120	25
10	Breton	6.2	35	45	20	16.0	0.08	2	1	155	50
11	Athabasca	5.5	34	52	14	14.3	0.14	1	1	100	63
12	Jarvie	7.5	14	47	39	47.0	0.47	4	4	145	260

<sup>a</sup> in 0.01 M CaCl<sub>2</sub>



case part of this source of nitrogen would not be readily available to the crop. The fertilization of a second portion of each soil with sodium nitrate was to serve as a standard against which the degree to which ammonium was unavailable to the indicator crop could be estimated. The effect of native nitrogen in each soil was measured by plant uptake of N from soil not fertilized with this nutrient.

The rate of application for N at 30 ppm was chosen to ensure the initial development of the crop in the nitrogen treated soils. Further, at this rate the nitrogen supply would be exhausted after a reasonable period of growth which would put the plants under nitrogen stress and allow an appraisal of the extent to which the added ammonium was fixed and not available to the rape crop. In both experiments extensive chlorosis, symptomatic of N deficiency, was shown by all plants before they had reached the flowering stage. This indicated the depletion of available nitrogen in the soil, and since vegetative growth was no longer evident the plants were harvested at the early flowering stage. The yield data of the greenhouse experiments are reported in Appendices B and C.

The analyses of variance (Tables 5 and 6) show that treatments and soils contributed by far the greatest to the variability in these experiments. For the individual soils, mean yields of four replicates and comparisons of treatment differences by Duncan's Multiple Range Test are presented in Tables 7 and 8. In the first experiment (Table 7), yields of dry matter were higher from applications of nitrate N than from ammonium N for all soils except Hughenden. However, yield differences between the two sources of N were not



TABLE 5. Analyses of variance for yields of dry matter and of nitrogen from rape grown on Chernozemic soils (First greenhouse experiment)

Source of variation	Degrees of freedom	Sums of squares	Mean square	F value
<u>Yield of dry matter</u>				
Replicates	3	0.193	0.064	4.29*
Soils	5	3.376	0.675	45.00**
Error A	15	0.227	0.015	
Treatments	2	15.770	7.885	438.06**
Treatments x Soils	10	0.554	0.055	3.06**
Error B	36	0.665	0.018	
Total	71	20.785		
<u>Yield of nitrogen</u>				
Replicates	3	49.0	16.3	0.12
Soils	5	5,977.2	1,195.4	8.98**
Error A	15	1,996.7	133.1	
Treatments	2	26,567.8	13,283.6	1,037.78**
Treatments x Soils	10	270.2	27.0	2.11
Error B	36	462.7	12.8	
Total	71	33,428.1		

Levels of significance: \*\*: 0.01

\*: 0.05





TABLE 6. Analyses of variance for yields of dry matter  
and of nitrogen from rape grown on Luvisolic soils  
(Second greenhouse experiment)

Source of variation	Degrees of freedom	Sums of squares	Mean square	F value
<u>Yield of dry matter</u>				
Replicates	3	0.099	0.033	16.50**
Soils	5	7.346	1.469	734.50**
Error A	15	0.030	0.002	
Treatments	2	21.252	10.626	559.26**
Treatments x Soils	10	0.823	0.082	4.32**
Error B	36	0.670	0.019	
Total	71	30.220		
<u>Yield of nitrogen</u>				
Replicates	3	77.2	25.7	23.36**
Soils	5	8,817.8	1,763.6	1,603.27**
Error A	15	16.4	1.1	
Treatments	2	19,799.5	9,899.8	1,010.18**
Treatments x Soils	10	659.2	65.9	6.72**
Error B	36	353.1	9.8	
Total	71	29,723.2		

Level of significance: \*\*: 0.01



TABLE 7. Mean yields of dry matter and of nitrogen from rape grown on Chernozemic soils (First greenhouse experiment)

Soil	Source of N applied	Dry matter g/pot	Nitrogen mg/pot
1 Fawcett	NO <sub>3</sub>	2.43 a	69.4 a
	NH <sub>4</sub>	2.18 a	57.2 a
	NIL	0.92 b	20.2 b
2 Hughenden	NO <sub>3</sub>	2.51 a	92.3 a
	NH <sub>4</sub>	2.65 a	86.0 a
	NIL	1.78 a	47.5 b
3 Ponoka	NO <sub>3</sub>	2.02 a	73.8 a
	NH <sub>4</sub>	1.90 a	67.8 a
	NIL	1.10 a	27.2 b
4 Angus Ridge	NO <sub>3</sub>	2.15 a	67.5 a
	NH <sub>4</sub>	2.04 a	60.8 a
	NIL	1.07 a	25.1 b
5 Malmo	NO <sub>3</sub>	2.04 a	70.0 a
	NH <sub>4</sub>	2.00 a	66.6 a
	NIL	1.06 a	21.2 b
6 Majeau	NO <sub>3</sub>	2.14 a	64.0 a
	NH <sub>4</sub>	2.07 a	54.6 ab
	NIL	1.19 a	27.9 b

a-b Means in each column for each soil followed by the same letter are not significantly different by Duncan's multiple range test at  $p = 0.05$ .



TABLE 8. Mean yields of dry matter and of nitrogen from rape grown on Luvisolic soils (Second greenhouse experiment)

Soil	Source of N applied	Dry matter g/pot	Nitrogen mg/pot
7 Cooking Lake	NO <sub>3</sub>	2.50 a	77.5 a
	NH <sub>4</sub>	2.38 ab	71.4 a
	NIL	1.38 b	32.5 a
8 Breton	NO <sub>3</sub>	2.16 a	62.1 a
	NH <sub>4</sub>	1.99 a	54.3 a
	NIL	0.72 b	17.8 b
9 La Corey	NO <sub>3</sub>	2.28 a	64.6 a
	NH <sub>4</sub>	2.04 a	59.0 ab
	NIL	0.92 b	23.1 b
10 Breton	NO <sub>3</sub>	1.75 a	42.0 a
	NH <sub>4</sub>	1.45 a	32.1 ab
	NIL	0.33 b	6.8 b
11 Athabasca	NO <sub>3</sub>	1.71 a	44.6 a
	NH <sub>4</sub>	1.40 ab	36.8 ab
	NIL	0.44 b	12.7 b
12 Jarvie	NO <sub>3</sub>	1.78 a	57.4 a
	NH <sub>4</sub>	1.40 a	44.5 ab
	NIL	0.90 a	23.6 b

a-b Means in each column for each soil followed by the same letter are not significantly different by Duncan's multiple range test at  $p = 0.05$ .



significant. Both nitrogen sources approximately doubled the yield of dry matter over that of the check, but only on the Fawcett soil was this increase significant, indicating the variability in the experiment. The uptake of nitrogen was higher from added nitrate N than from ammonium N, but again these differences were not significant. Increases over the check were significant from both nitrogen sources for all soils except Majeau for which only the increase from nitrate treatment was significant.

The effects of ammonium and nitrate treatments on yields from the individual soils are further shown in Figure 7. The columns represent means of net yields (treatment yields minus check yields) as computed per kg of soil. Net yields of dry matter from either source of N were highest for Fawcett soil which in this group was lowest in content of native available N, and were lowest for Hughenden soil which had 24 ppm native nitrate N. The difference in net yield of dry matter between these two soils shows that the relatively high amount of native nitrate N in Hughenden soil depressed the response of rape to applied N in this experiment. This effect could be minimized by removal of native available N by cropping the soil prior to use in soil nutrient experiments.

The columns for uptake of N show for each soil the recovery of applied N. Recovery of applied ammonium N ranged from 56 to 82% and that of applied nitrate N from 77 to 89% for this group of soils. Differences in recovery between the two sources of N were least for Malmo soil which had a relatively high fixing capacity, and were highest for the low fixing Fawcett soil. For all soils in this group the graph shows that differences in recovery were not consistent with





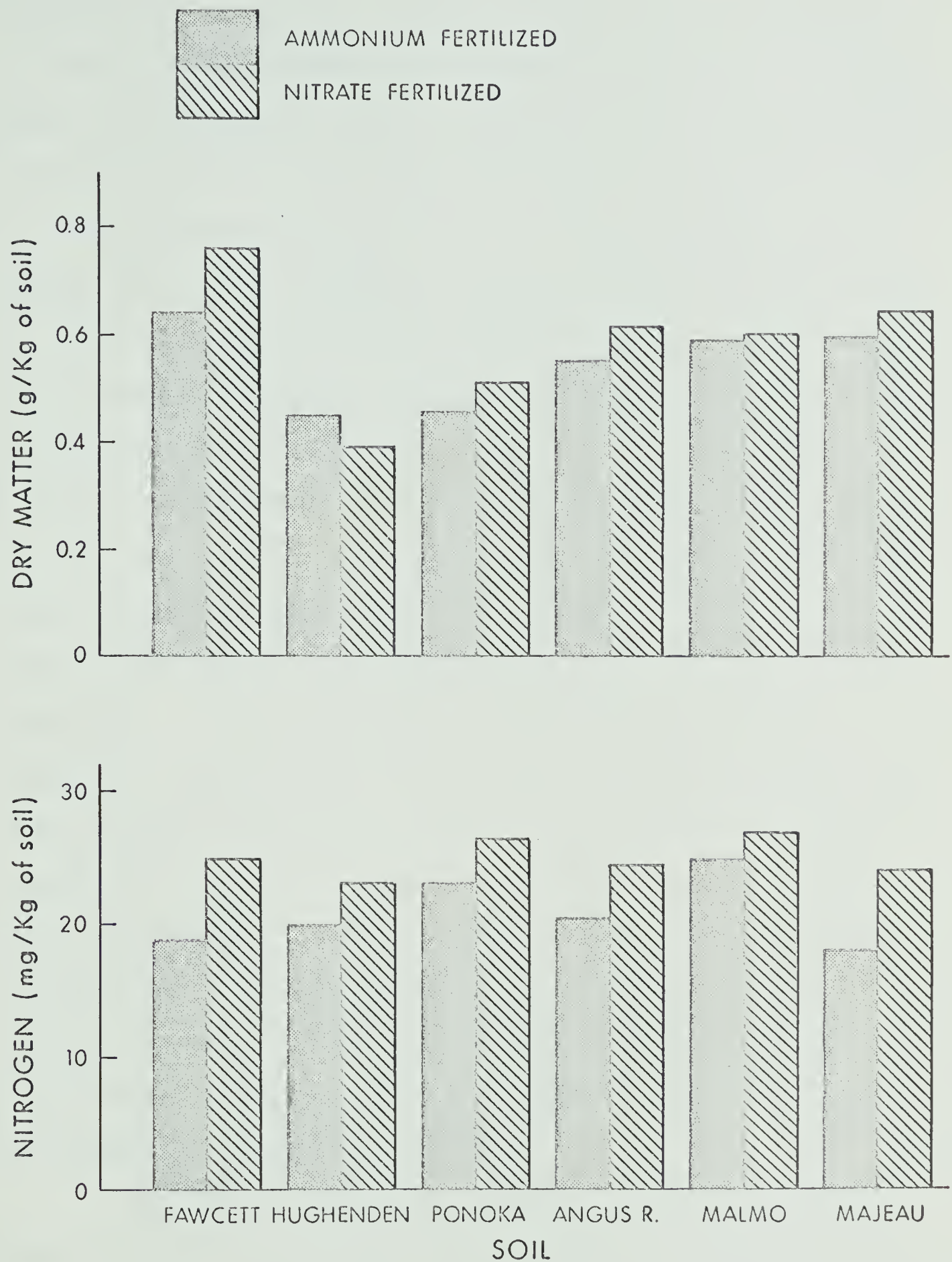


Figure 7. Effects of ammonium and nitrate fertilization on yields of dry matter and of nitrogen from rape grown on Chernozemic soils (First greenhouse experiment). Fixing capacities increase from left to right.



ammonium fixing capacities. Instead, possible effects of fixation on nitrogen uptake appeared to be offset by mineralization of organic matter in the Chernozemic soils. To minimize effects of mineralization, a group of Luvisolic soils of low organic matter content was selected for the second greenhouse experiment for which mean yields and comparisons of treatment differences are shown in Table 8. For all soils the yields were highest from added nitrate N, lowest from the check and intermediate from added ammonium N, both for dry matter yield and for nitrogen uptake. For La Corey soil and the two Breton soils, dry matter yields from both sources of N were significantly higher than the check yields; for the Cooking Lake and Athabasca soils, only yields from added nitrate N were significantly higher than the check yields; and for Jarvie soil differences in dry matter yield were not significant. For nitrogen uptake, treatment differences were not significant on Cooking Lake soil; they were significant between either of the nitrogen sources and the check on Breton (8) soil; they were significant only between nitrate N and the check on the La Corey, Breton (10), Athabasca and Jarvie soils. Although the increase of nitrogen uptake from ammonium N over the check ranged from nearly double on Jarvie soil to more than fourfold on Breton (10) soil, this difference was only significant on Breton (8) soil indicating the variability also in this experiment.

The effects of ammonium and nitrate treatment are further shown in Figure 8. The columns represent means of treatment yields minus check yields computed per kg of soil. Differences between the two sources of N are shown to be greater in soils of relatively





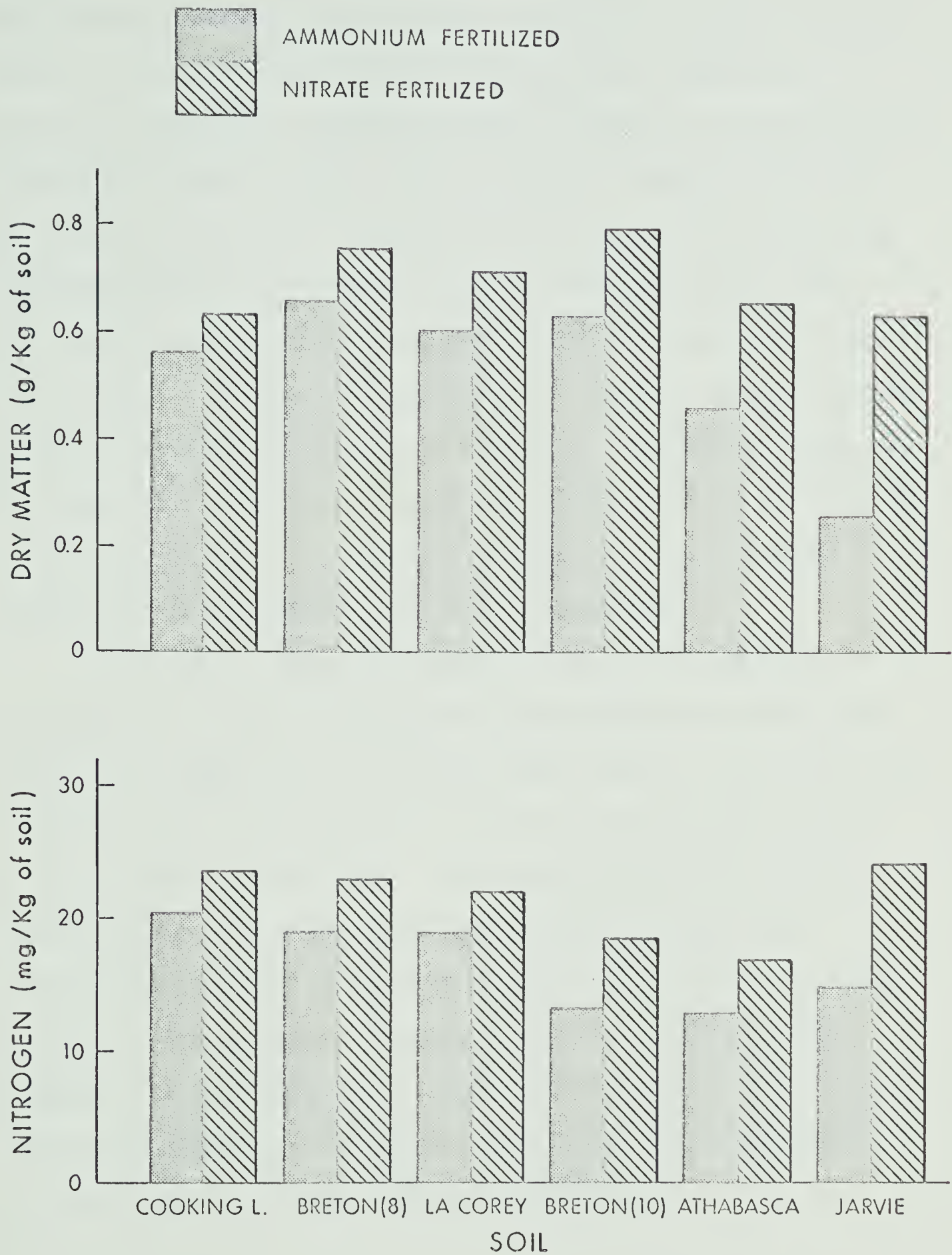


Figure 8. Effects of ammonium and nitrate fertilization on yields of dry matter and of nitrogen from rape grown on Luvisolic soils (Second greenhouse experiment). Fixing capacities increase from left to right.



high fixing capacities than in soils in which this capacity was low. However, these differences were not statistically significant, as discussed previously. Recovery of added nitrogen as depicted by the columns for N-uptake ranged from 42 to 68% for ammonium N and from 56 to 80% for nitrate N. Recoveries of both ammonium and nitrate N were particularly low for Breton (10) and Athabasca soils. The poor structure in these soils was unfavorable for plant growth and denitrification resulting from insufficient aeration may have accounted for the notably low recovery of nitrate N. Jarvie soil, which had the highest fixing capacity, showed the highest recovery of nitrate N in this experiment and the greatest difference between nitrogen uptake from the two sources of N in both experiments.

Correlation values were computed for ammonium fixing capacities of the 12 soils versus the mean differences between the yields of dry matter and of nitrogen uptake from the two sources of N ( $r = 0.48$  and  $r = 0.49$  for yield differences of dry matter and for nitrogen uptake, respectively). These values uphold the earlier observation that the differences between yields of rape from ammonium and nitrate N were not consistent with the ammonium fixing capacities of these soils. The correlation was not improved by computing the mean differences as per cent of nitrogen uptake from nitrate treatment ( $r = 0.44$  and  $r = 0.54$  for yield differences of dry matter and for nitrogen uptake, respectively).





#### D. Incubation experiments

Two incubation experiments were conducted concurrently with the greenhouse experiments. They involved the 12 soils used in the greenhouse studies and were intended to assess the effect of the fixation properties of these soils on nitrification of added ammonium.

The soils were treated with 50 ppm of nitrogen, one portion of each soil with ammonium N, a second portion with nitrate N, and a third portion was left untreated as a check. The rate of 50 ppm was selected to add an amount of nitrogen that would be in excess of average amounts of N expected to be mineralized in these soils. The treatment with nitrate nitrogen served as a standard against which the nitrification of added ammonium could be measured. The soils were analyzed for exchangeable ammonium and for nitrate immediately after the incubation period of 35 days and the results of the analyses are reported in Appendices D and E.

The results show that with few exceptions the samples contained less than 1 ppm of exchangeable ammonium which indicated that nitrification of exchangeable ammonium had proceeded to completion. The analyses of variance in Table 9 show that treatments and soils contributed by far the greatest to the variability in these experiments, analogous to the greenhouse experiments. Mean contents of nitrate N for four replicates and comparisons of treatment differences for each soil by Duncan's Multiple Range Test are presented in Tables 10 and 11. For all soils, the nitrate content was higher in the samples treated with nitrate N than in those treated with ammonium N, and was lowest in the check samples. For



TABLE 9. Analyses of variance for content of nitrate nitrogen in 12 soils supplied with two sources of N and incubated for 35 days (Two experiments with six soils each)

Source of variation	Degrees of freedom	Sums of squares	Mean square	F value
<u>First incubation experiment</u>				
Replicates	3	14.6	4.9	0.59
Soils	5	4,665.3	933.1	112.42**
Error (A)	15	125.1	8.3	
Treatments	2	40,345.1	20,172.6	4,116.86**
Treatments x Soils	10	783.1	78.3	15.98**
Error (B)	36	175.3	4.9	
Total	71	46,108.5		
<u>Second incubation experiment</u>				
Replicates	3	13.2	4.4	0.44
Soils	5	12,322.7	2,464.5	248.94**
Error (A)	15	148.9	9.9	
Treatments	2	28,519.4	14,259.7	2,376.62**
Treatments x Soils	10	1,119.2	111.9	18.65**
Error (B)	36	216.3	6.0	
Total	71	42,339.7		

Level of significance: \*\*: 0.01



TABLE 10. Mean contents of nitrate nitrogen in  
Chernozemic soils supplied with two sources  
of N and incubated for 35 days  
(First incubation experiment)

Soil		Source of N applied	NO <sub>3</sub> -N ppm
1	Fawcett	NO <sub>3</sub>	90.4 a
		NH <sub>4</sub>	84.0 a
		NIL	40.0 b
2	Hughenden	NO <sub>3</sub>	112.4 a
		NH <sub>4</sub>	104.7 a
		NIL	61.3 b
3	Ponoka	NO <sub>3</sub>	121.6 a
		NH <sub>4</sub>	108.4 a
		NIL	55.8 b
4	Angus Ridge	NO <sub>3</sub>	112.6 a
		NH <sub>4</sub>	100.5 a
		NIL	56.0 b
5	Malmo	NO <sub>3</sub>	116.0 a
		NH <sub>4</sub>	102.4 a
		NIL	57.6 b
6	Majeau	NO <sub>3</sub>	105.6 a
		NH <sub>4</sub>	86.6 a
		NIL	57.0 b

a-b Means for each soil followed by the same  
letter are not significantly different by  
Duncan's multiple range test at  $p = 0.05$ .



TABLE 11. Mean contents of nitrate nitrogen in Luvisolic soils supplied with two sources of N and incubated for 35 days (Second incubation experiment)

Soil		Source of N applied	NO <sub>3</sub> -N ppm
7	Cooking Lake	NO <sub>3</sub>	94.5 a
		NH <sub>4</sub>	84.4 a
		NIL	46.0 b
8	Breton	NO <sub>3</sub>	88.4 a
		NH <sub>4</sub>	77.3 a
		NIL	39.4 b
9	La Corey	NO <sub>3</sub>	105.5 a
		NH <sub>4</sub>	89.3 a
		NIL	58.3 b
10	Breton	NO <sub>3</sub>	61.0 a
		NH <sub>4</sub>	49.5 a
		NIL	16.5 b
11	Athabasca	NO <sub>3</sub>	88.2 a
		NH <sub>4</sub>	72.6 a
		NIL	40.2 b
12	Jarvie	NO <sub>3</sub>	104.2 a
		NH <sub>4</sub>	68.6 b
		NIL	53.6 b

a-b Means for each soil followed by the same letter are not significantly different by Duncan's multiple range test at  $p = 0.05$ .





all soils except Jarvie, treatment differences between either source of N and the check were significant, but treatment differences between the two sources of N were not significant. For the Jarvie soil, treatment differences between nitrate N and the check and between the two sources of N were significant, but the difference between ammonium N and the check was not significant.

The graphical representation of the incubation results in Figure 9 is based on the net contents of nitrate N (treatment content minus check content) in the ammonium and nitrate treated soils after incubation. The columns show the effects of ammonium and nitrate treatments for each soil and the amounts of nitrogen recovered from that applied. In four soils, Ponoka, Angus Ridge, Malmo and Jarvie, nitrate recovery exceeded nitrate addition and in the Ponoka soil an excess recovery was also recorded for added ammonium. It appears that in these soils mineralization was stimulated by treatment resulting in a gain of nitrate N in the treated samples during incubation. The differences in nitrate content from ammonium and nitrate treatments are shown to be greater for most soils of relatively high fixing capacities than for the low fixing soils. This observation is supported by the correlation value for ammonium fixing capacities versus treatment mean differences ( $r = 0.89$ ) which was nearly identical to the correlation value for fixing capacities versus mean differences as per cent of nitrate recovery ( $r = 0.91$ ). Thus in these soils, mean differences from ammonium and nitrate treatments as measured in the experiments were consistent with ammonium fixing capacities.

A third incubation experiment was conducted with four soils



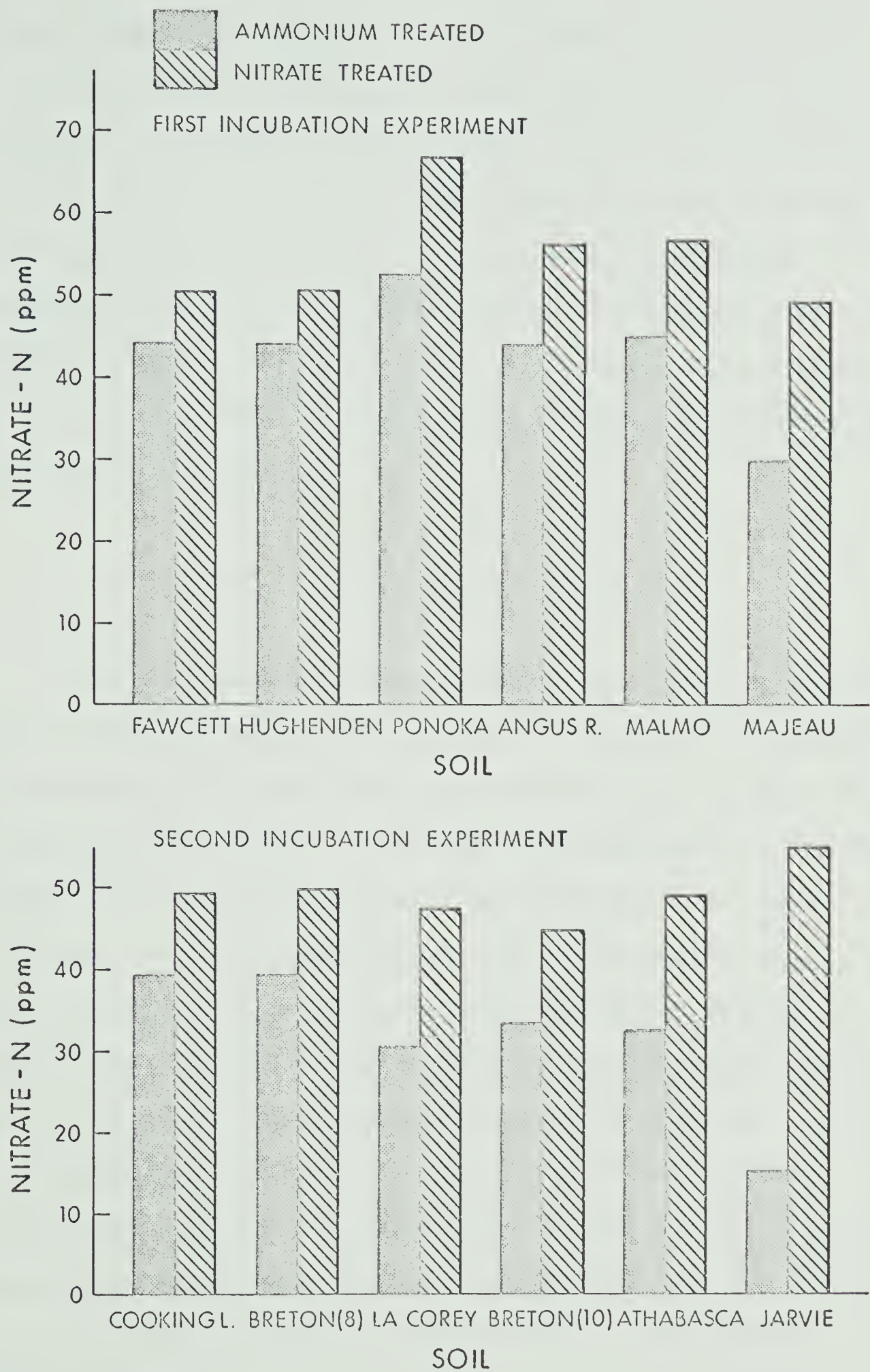


Figure 9. Effects of ammonium and nitrate treatments on nitrate content in 12 soils after incubation. Fixing capacities increase from left to right.



(Fawcett, Angus Ridge, Majeau, Jarvie) pretreated with 50 ppm K as KCl. This experiment was intended to study the blocking effect of potassium on the fixation of added ammonium. The results (Appendix F) showed that in these soils the treatment differences from additions of ammonium and nitrate were similar to the treatment differences recorded for these soils without the addition of potassium in the incubation studies discussed previously. As measured in this experiment, the blocking effect of potassium did not affect the fixation of added ammonium in these soils.

#### E. Solution culture experiments

The greenhouse experiments indicated that growth of rape was superior after fertilization with nitrate N as compared to fertilization with ammonium N. Since this phenomenon occurred in all 12 soils studied and was not well correlated to ammonium fixing capacities of the soils it appeared that other factors may have contributed to the observed differences. It has been demonstrated that plant response to ammonium and nitrate N varies considerably according to species (Pirschle, 1929, 1931), but this response is also influenced by such factors as pH and nutrient concentration of the growth medium. Furthermore, oats has been reported to be more effective than rape in utilizing added ammonium from fixing soils (Nommik, 1965). Thus, an experiment was initiated to observe the response of oats and rape to ammonium and nitrate nitrogen in culture solution. Nitrogen was supplied at 84 ppm.





The inferior growth of both crops in ammonium solution as compared to nitrate is shown by the yields of dry matter presented in Table 12. Oats and particularly rape were adversely affected in the ammonium solution, which indicated that the concentration of ammonium N was too high. Both, oats and rape grew well in nitrate solutions of the same concentrations. Plant growth in the culture solutions after 26 days is depicted in Plate 1.

The objective of a second experiment was to investigate the response of rape to ammonium nitrogen at much lower rates than the rate used in the first experiment and to compare crop responses from the ammonium solutions to those from nitrate solutions of corresponding concentrations. Nitrogen was supplied at 3.5, 7.0 and 14.0 ppm. The data for dry matter yield and nitrogen uptake (Table 13) show that the response of rape was nearly identical for the two sources of nitrogen at 3.5 and 7.0 ppm N. At 14.0 ppm N, yield of dry matter from nitrate N was almost double of that from ammonium N. The uptake of nitrogen from the two sources at this rate was less markedly affected and was only slightly lower for uptake of ammonium N as compared to that of nitrate N. However, differences in appearances of the crop were considerable for the two sources of N at 14.0 ppm which, together with growth appearances at the two other rates, are shown in Plate 2.

Data and observations from these experiments suggest that except for very low rates, rape plants are considerably affected when supplied with ammonium N as the only source of nitrogen. They further indicate that rape has a low tolerance to high concentrations of ammonium and that this crop has a marked preference for the uptake of nitrate N over ammonium N.





TABLE 12. Dry matter yields<sup>a</sup> (g) of oats and rape grown in ammonium and nitrate solution cultures at 84 ppm of N

Solution	Oats		Rape	
	NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>
Tops	1.86	4.18	0.58	7.27
Roots	0.55	1.56	0.08	1.37
Total	2.41	5.74	0.66	8.64

<sup>a</sup> Means of 3 replicates

TABLE 13. Dry matter yield and nitrogen uptake of rape grown in ammonium and nitrate solutions culture at three rates of N

Rate of N (ppm)	3.5		7.0		14.0	
	NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>
<u>Dry matter yield (g)<sup>a</sup></u>						
Tops	2.22	2.26	3.55	3.63	3.74	6.27
Roots	0.61	0.82	0.86	1.08	0.72	1.73
Total	2.83	3.08	4.41	4.71	4.46	8.00
<u>Nitrogen uptake (mg)<sup>a</sup></u>						
Tops	46.4	44.5	83.3	79.5	133.1	129.7
Roots	11.3	13.1	17.8	20.2	25.4	36.0
Total	57.7	57.6	101.1	99.7	158.5	165.7

<sup>a</sup> Means of 2 replicates



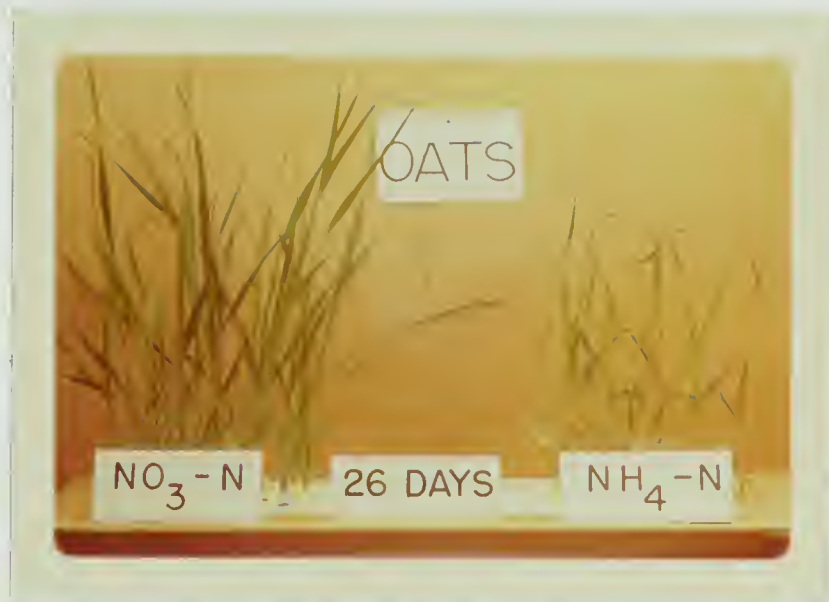


Plate 1. Growth of oats and rape in ammonium and nitrate culture solutions at 84 ppm N.





Plate 2. Growth of rape in ammonium and nitrate culture solutions at three rates of N.





## SUMMARY AND CONCLUSIONS

It is well known that some soils have the ability to bind added ammonium in such a manner that it will not be readily exchangeable by the usual methods of cation exchange. This fixation is attributed to the mineral fraction of the soil and in particular to lattice clay minerals with an expansible interlattice spacing. Fixed ammonium is arbitrarily defined as ammonium not extracted by an equilibrium method with 2 N KCl. More important, the ability of a soil to fix added ammonium may render this ion biologically only difficultly available.

The lack of information regarding ammonium fixation in Alberta soils led to the current study, for which over one hundred surface samples were collected. These samples represented a wide range of cultivated soils in the Dark Brown, Black and Gray Wooded soil zones in central and northern Alberta. The main objectives of the investigation were:

- (a) to determine in the laboratory the ammonium fixing capacities of all the soils collected and to ascertain on selected soils the fixation of ammonium when added at rates comparable to those used for crop production under field conditions and
- (b) to study on selected soils biological effects of ammonium and nitrate treatments in greenhouse and incubation experiments.

The capacity of the soils to fix added ammonium was determined by holding samples in ammonium solutions of appropriate concentrations and by extracting the exchangeable ammonium with 2 N KCl. Fixation was





calculated as the amount of added ammonium that was not extracted.

The effect of ammonium and nitrate fertilization on plant growth was studied with 12 selected soils in greenhouse experiments using rape as the indicator crop. The plants were allowed to grow for 35 days at which time strong chlorosis indicated that the added amounts of nitrogen were depleted. These same selected soils were used for incubation studies intended to determine the extent of nitrification of added ammonium in soils of different fixation properties. Solution culture experiments were conducted to compare plant growth in ammonium solutions to that in nitrate solutions.

The following conclusions can be drawn from the material presented:

- (a) The majority of surface soils have low capacities to fix added ammonium and only rarely does this capacity exceed 100 ppm of ammonium N. Considerable variation in fixing capacities occurs within short distances in the field as well as within soil series at different locations.
- (b) The uniformity of fixation of ammonium added at low rates shows that most soils fix some of the ammonium added at practical rates, but the fixing capacity of a soil must be high before fixation of added ammonium at practical rates is appreciable. Fixation of added ammonium was enhanced in several soils after drying at 30<sup>o</sup> C. Thus, fixation of added ammonium under dry conditions in the field could be of practical significance.



- (c) The uptake of nitrogen by rape from ammonium and nitrate fertilization was decidedly in favor of the nitrate treatment. Correlation of ammonium fixing capacities with mean differences of dry matter yield from the two sources of N indicated a weak relationship between plant response and fixing capacity ( $r = 0.48$ ) and was nearly identical to the correlation between fixing capacity and nitrogen uptake ( $r = 0.49$ ).
- (d) Nitrification of added ammonium, when compared to utilization of added nitrate, was highly correlated with ammonium fixing capacities ( $r = 0.89$ ). This suggests that ammonium fixed after being added is not available for nitrification by microorganisms even under conditions favorable for microbial activity as was the case for the incubation experiments.
- (e) The solution culture experiments confirmed the observation made in the greenhouse that for rape nitrate N was the preferred source of nitrogen over ammonium N. This preference for nitrate N may account for the low correlation between fixing capacity and crop yield shown in the greenhouse experiments.

The foregoing investigations on the fixation and availability of ammonium in Alberta soils were conducted under laboratory and greenhouse conditions and the results are therefore not readily applicable to field conditions. However, the indications are that for some soils the fixation of ammonium may be of practical significance, especially if ammonium fertilizers are applied extensively. Field trials would be necessary to assess the agronomic significance of fixation of added ammonium in these soils.



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APPENDIX A. AMMONIUM FIXING CAPACITY OF 101 SURFACE SOILS,  
GROUPED BY SAMPLING AREAS, AND SHOWING CLASSIFICATION  
AND LEGAL LOCATIONS

Subgroup	Series	Legal location	Ammonium fixing capacity ppm <sup>a</sup>
<u>Peace River Area</u>			
Orthic Black	Bronco	SE-17-78- 4-6	94
Eluviated Black	Peoria	NW-15-80- 8-6	11
" "	"	SE- 9-71- 8-6	55
" "	"	NW- 9-78-15-6	39
" "	Sexsmith	NW-15-80- 8-6	77
" "	"	SW-31-73- 6-6	36
" "	"	SW-16-73- 6-6	50
Gleyed Black-	High Prairie (1)	-- 74-16&17-5	24
Gleyed Dark Gray	" " (2)	"	60
(complex)	" " (3)	"	45
" "	" " (4)	"	60
" "	" " (5)	"	70
Black Solod	Albright	NW-36-71-10-6	38
" "	Fahler	NW-13-79-13-6	59
" "	Landry	NW-23-70-22-5	7
" "	"	NW-15-80- 8-6	7
" "	"	SE-26-72- 5-6	7
" "	"	NW-15-80- 8-6	13
" "	"	SE- 9-71- 8-6	68
" "	"	NW- 9-78-15-6	32

<sup>a</sup> Average of duplicates





APPENDIX A. (continued)

Subgroup	Series	Legal location	Ammonium fixing capacity ppm
Black Solod	Landry	NW-15-80- 8-6	36
" "	"	SW-31-73- 6-6	25
" "	"	SW-16-73- 6-6	45
" "	"	SE-30-70-22-5	18
" "	"	NW-12-73- 8-6	20
" "	"	SW-35-77- 3-6	17
" "	Mytron	SW- 5-86-18-6	73
" "	Rycroft	SE-30-70-22-5	14
" "	"	NW-12-73- 8-6	10
" "	"	SW-35-77- 3-6	8
" "	Valleyview	NW-23-70-22-5	10
" "	"	NW-15-80- 8-6	32
" "	"	SE-26-72- 5-6	11
Gray Solod	Debolt	NE-25-72- 1-6	29
" "	"	NW-34-71- 9-6	22
" "	Donnelly	-- 26-72- 1-6	6
" "	"	NE-32-79-12-6	38
" "	Hazelmere	NW- 2-70-12-6	38
" "	Nampa	SW- 2-78-20-5	46
" "	"	NW-13-79-13-6	22
" "	"	-- -- 74-18-5	35
Orthic Gray	Alcan	SW-12-78-16-6	34
Luvisol	"	SE- 3-85-15-6	1
"	"	SE-21-78-16-6	0
"	"	SW- 6-80-16-6	14



APPENDIX A. (continued)

Subgroup	Series	Legal location	Ammonium fixing capacity ppm
Orthic Gray Luvisol	Alcan	Prespaton Creek Valley 35 miles N of Fort St. John	15
"	"	Mile 19, Beaton River Road 40 miles NNW of Fort St. John	13
"	Braeburn	-- 20-10-19-5	20
"	"	NE-34-74- 4-6	24
"	Culp	SW- 9-78-23-5	17
"	Demmitt	NE-11-73-12-6	34
"	Kathleen	NW-22-79- 8-6	81
"	"	near Triangle, Alta.	53
Dark Gray Luvisol	Hythe	SW- 3-71-12-6	64
	Saddle	SW- 6-71-19-5	25
Humic Eluviated Gleysol	Josephine	SE-15-82-10-6	20
<u>Northeast Area</u>			
Orthic Gray Luvisol	Athabasca	SW-26-67-16-4	25
"	"	SW-19-67-15-4	18
"	"	NW-30-65-14-4	63
"	"	SW- 1-66-15-4	36
"	La Corey	NW-31-59-12-4	25
"	"	SE-13-60-13-4	25



APPENDIX A. (continued)

Subgroup	Series	Legal location	Ammonium fixing capacity ppm
<u>Northwest Area</u>			
Orthic Black	Penhold	SW-33-59- 1-5	94
Solodic Dark	Majeau	NW-13-56- 3-5	112
Gray	"	NW- 6-56- 2-5	35
"	"	NE-35-56- 4-5	66
Black Solod	Kavanagh	SE-12-61- 2-5	25
Dark Gray	Fawcett	NW-11-64-27-4	7
Luvisol			
Orthic Gray	Cooking Lake	NW- 8-56- 3-5	66
Luvisol	" "	SE-17-58- 1-5	45
"	" "	SE-28-62-26-4	38
"	" "	SE-21-53- 2-5	25
"	Glory	NE-19-60- 6-5	67
"	Hubalta	-- -- 59-12-5	25
"	Kathleen	-- -- 57- 8-5	46
"	"	NE-36-59- 5-5	4
Humic Eluviated	Jarvie	NW-12-64- 1-5	260
Gleysol			
<u>Central Area</u>			
Orthic Black	Malmo	NE-24-51-25-4	80
Eluviated Black	Angus Ridge	SE-11-54-22-4	48
" "	Ponoka	NE-24-40-27-4	25



APPENDIX A. (continued)

Subgroup	Series	Legal location	Ammonium fixing capacity ppm
Orthic Gray Luvisol	Breton	NW-29-41-23-4	22
"	"	NE-25-47- 4-5	50
"	Cooking Lake	SE-28-52-21-4	18
<u>East-Central Area</u>			
Orthic Dark Brown	Hughenden	SE-27-40-12-4	20
"	"	NW-14-41-10-4	17
"	"	SW-13-39- 3-4	31
"	"	SE- 1-41- 7-4	52
"	"	SE- 5-41- 6-4	40
"	"	NE- 1-45- 4-4	14
"	"	NW- 2-45- 2-4	28
"	"	SW-23-45- 2-4	34
"	Metisko	SW-22-41- 8-4	7
Solodic Dark Brown	series not established	NE-30-39- 3-4	24
Orthic Black	Elnora	NW-32-44-10-4	4
Orthic Black (on alluvial material)	series not established	SW-32-46- 8-4	13
Black Solod	Daysland	NW-10-42-12-4	15
" "	"	SW-22-44-15-4	9
" "	"	NW- 4-46- 7-4	32
" "	"	SE- 3-45- 6-4	53
" "	Killam	SW-15-41-15-4	21
" "	"	SW-13-44-16-4	8





APPENDIX B. YIELD OF RAPE FROM SIX SOILS FERTILIZED WITH EITHER AMMONIUM OR NITRATE NITROGEN  
(First greenhouse experiment)

Soils <sup>a</sup>	Ammonium fixation capacity ppm	Source of N <sup>b</sup> applied <sup>c</sup>	Replicate											
			I			II			III			IV		
			Yield <sup>c</sup> g/pot	N <sup>d</sup> %	Yield of N mg/pot	Yield g/pot	N %	Yield of N mg/pot	Yield g/pot	N %	Yield of N mg/pot	Yield g/pot	N %	Yield of N mg/pot
1 Fawcett	7	NO <sub>3</sub>	2.48	2.39	59.2	2.59	2.82	73.0	2.42	3.01	72.8	2.23	3.38	71.1
		NH <sub>4</sub>	2.36	2.52	59.4	2.09	2.60	54.4	2.10	2.83	59.5	2.17	2.93	52.4
		NIL	1.10	2.00	21.9	0.93	2.10	20.0	0.83	2.14	17.7	0.83	2.45	25.5
2 Hughenden	20	NO <sub>3</sub>	2.44	3.78	92.2	2.53	3.54	90.0	2.70	3.34	90.3	2.38	3.69	77.0
		NH <sub>4</sub>	2.56	3.21	82.2	2.72	3.14	85.3	2.53	3.51	88.7	2.80	3.75	69.5
		NIL	1.96	2.32	45.4	1.77	2.66	53.0	1.78	2.56	45.6	1.61	2.58	26.8
3 Ponoka	25	NO <sub>3</sub>	1.92	3.84	73.7	2.28	3.35	76.3	2.04	3.50	71.3	1.84	3.22	69.3
		NH <sub>4</sub>	2.02	3.30	66.8	1.98	3.36	66.7	1.93	3.46	66.7	1.68	2.82	60.2
		NIL	1.18	2.37	27.9	1.20	2.58	31.0	1.02	2.48	25.3	1.01	2.38	26.3
4 Angus Ridge	48	NO <sub>3</sub>	1.99	3.30	55.7	2.30	2.88	66.2	2.15	3.20	68.8	2.15	4.00	73.7
		NH <sub>4</sub>	2.10	2.76	58.1	1.90	3.03	57.7	2.00	3.36	67.0	2.14	4.22	71.0
		NIL	1.12	2.25	25.1	1.08	2.41	26.0	0.99	2.34	23.1	1.10	2.45	24.7
5 Malmo	80	NO <sub>3</sub>	2.06	3.31 <sup>d</sup>	68.3	1.98	3.46	68.4	2.05	3.24	66.5	2.09	4.06	96.7
		NH <sub>4</sub>	2.19	3.09	67.5	1.96	3.17	62.0	2.01	3.36	67.5	1.85	3.14	88.0
		NIL	1.15	2.28	26.2	1.03	2.49	25.6	1.01	2.57	26.0	1.04	2.85	46.0
6 Majean	112	NO <sub>3</sub>	2.08	2.84	59.0	2.23	2.84	63.4	2.14	2.93	62.7	2.10	3.25	72.6
		NH <sub>4</sub>	2.25	2.60	58.4	2.10	2.43	51.1	2.13	2.66	56.7	1.79	2.60	56.4
		NIL	1.38	2.24	31.0	1.12	2.48	27.8	1.21	2.26	27.4	1.04	2.54	21.1

<sup>a</sup> Classification of soils in table 1 (p.22)

<sup>b</sup> N applied at 30 ppm

<sup>c</sup> Plant material dried at 65° C

<sup>d</sup> Average of duplicates



APPENDIX C. YIELD OF RAPE FROM SIX SOILS FERTILIZED WITH EITHER AMMONIUM OR NITRATE NITROGEN  
(Second greenhouse experiment)

		Replicate												
		I			II			III			IV			
Soils <sup>a</sup>	Ammonium fixation capacity ppm	Source of N <sup>b</sup> applied	Yield <sup>c</sup>	N <sup>d</sup>	Yield of N	Yield	N	Yield of N	Yield	N	Yield of N	Yield	N	Yield of N
			g/pot	%	mg/pot	g/pot	%	mg/pot	g/pot	%	mg/pot	g/pot	%	mg/pot
7 Cooking Lake	18	NO <sub>3</sub>	2.49	3.24	80.8	2.60	3.06	79.6	2.63	2.95	77.6	2.29	3.14	72.0
		NH <sub>4</sub>	2.28	2.90	66.2	2.49	3.06	76.1	2.46	3.08	75.9	2.27	2.96	67.2
		NIL	1.22	2.44	29.7	1.32	2.46	32.5	1.28	2.55	32.6	1.42	2.47	35.2
8 Breton	22	NO <sub>3</sub>	2.17	2.82	61.2	2.10	3.03	63.8	2.24	2.72	60.9	2.12	2.94	62.4
		NH <sub>4</sub>	2.07	2.74	56.7	2.18	2.48	54.1	2.00	2.88	57.7	1.70	2.87	48.6
		NIL	0.73	2.41	17.6	0.75	2.46	18.7	0.67	2.54	17.1	0.74	2.37	17.6
9 La Corey	25	NO <sub>3</sub>	2.19	2.90	63.4	2.47	2.80	69.2	2.38	2.79	63.7	2.07	3.00	62.2
		NH <sub>4</sub>	2.29	2.76	63.2	2.00	2.67	53.4	1.98	3.16	62.6	1.90	2.98	56.7
		NIL	0.89	2.53	22.4	0.88	2.64	23.2	0.88	2.51	22.1	1.03	2.41	24.7
10 Breton	50	NO <sub>3</sub>	1.84	2.33	42.8	1.82	2.35	42.8	1.73	2.41	41.7	1.60	2.54	40.5
		NH <sub>4</sub>	1.47	2.18	31.5	1.43	2.14	30.5	1.56	2.17	33.9	1.34	2.42	32.5
		NIL	0.25	2.65	6.6	0.25	2.55	6.3	0.56	2.54	6.6	0.25	2.98	7.6
11 Athabasca	63	NO <sub>3</sub>	1.64	2.88	47.1	1.67	2.43	40.6	1.85	2.53	46.8	1.68	2.60	43.7
		NH <sub>4</sub>	1.23	2.65	32.6	1.43	2.52	35.9	1.50	2.62	39.2	1.43	2.75	39.4
		NIL	0.43	2.76	11.9	0.48	2.69	13.0	0.35	3.03	10.6	0.52	2.94	15.3
12 Jarvie	260	NO <sub>3</sub>	1.90	3.16	60.2	1.70	3.09	52.6	1.79	3.30	58.9	1.75	3.31	57.8
		NH <sub>4</sub>	1.19	3.42	40.7	1.56	3.02	47.0	1.36	3.24	44.0	1.50	3.09	46.4
		NIL	0.87	2.60	22.7	0.93	2.48	23.1	0.91	2.72	24.7	0.91	2.64	24.1

<sup>a</sup> Classification of soils in table 1 (p.22)

<sup>b</sup> N applied at 30 ppm

<sup>c</sup> Plant material dried at 65° C

<sup>d</sup> Average of duplicates



APPENDIX D. CONTENT (ppm) OF AMMONIUM AND NITRATE NITROGEN FROM SIX SOILS SUPPLIED WITH TWO SOURCES OF N AND INCUBATED FOR 35 DAYS (First incubation experiment)

Soils	Ammonium fixing capacity ppm	Source of N applied <sup>a</sup>	Replicate							
			I		II		III		IV	
			NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>
1 Fawcett	7	NO <sub>3</sub>	0.4	91.1	0.6	89.6	0.7	91.6	1.5	89.4
		NH <sub>4</sub>	0.4	81.9	0.8	82.3	0.6	85.0	0.9	86.8
		NIL	0.1	39.6	0.7	40.7	0.7	40.2	1.1	39.7
2 Hughenden	20	NO <sub>3</sub>	0.7	115.4	1.0	110.2	1.3	110.6	1.1	113.2
		NH <sub>4</sub>	0.8	104.3	0.9	106.2	0.7	103.5	2.2	104.8
		NIL	0.8	61.4	0.7	62.5	0.6	61.0	1.4	60.3
3 Ponoka	25	NO <sub>3</sub>	1.3	128.8	0.9	122.6	1.6	114.9	1.3	120.0
		NH <sub>4</sub>	1.0	107.9	0.8	112.3	1.7	106.8	2.3	106.4
		NIL	1.0	58.9	0.6	57.2	1.0	56.0	2.3	51.2
4 Angus Ridge	48	NO <sub>3</sub>	0.8	113.0	0.7	114.9	0.8	111.6	0.9	111.0
		NH <sub>4</sub>	0.8	99.4	0.9	103.1	0.9	99.2	0.5	100.3
		NIL	1.0	54.3	0.6	56.3	0.6	54.5	0.9	59.0
5 Malmo	80	NO <sub>3</sub>	0.9	113.4	0.9	114.9	1.3	120.0	1.1	115.8
		NH <sub>4</sub>	0.8	103.4	1.0	103.1	2.0	100.2	1.2	102.8
		NIL	0.3	58.1	1.0	60.7	1.6	57.1	1.2	54.6
6 MaJean	112	NO <sub>3</sub>	0.7	104.1	0.7	106.1	0.9	105.5	0.7	106.9
		NH <sub>4</sub>	0.5	87.4	0.5	85.1	0.9	86.7	0.8	87.3
		NIL	0.2	53.5	0.5	56.4	0.7	57.7	0.8	60.5

<sup>a</sup> N applied at 50 ppm



APPENDIX E. CONTENT (ppm) OF AMMONIUM AND NITRATE NITROGEN FROM SIX SOILS SUPPLIED WITH TWO SOURCES OF N AND INCUBATED FOR 35 DAYS (Second incubation experiment)

Soils	Ammonium fixing capacity ppm	Source of N applied <sup>a</sup>	Replicate							
			I		II		III		IV	
			NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub>	NO <sub>3</sub>
7 Cooking Lake	18	NO <sub>3</sub>	0.7	90.9	0.6	98.1	0.6	97.6	0.8	91.5
		NH <sub>4</sub>	0.8	84.8	0.7	87.0	0.7	83.9	0.8	81.8
		NIL	0.8	43.7	0.8	47.1	1.0	47.0	1.2	46.0
8 Breton	22	NO <sub>3</sub>	0.2	82.8	0.5	92.4	0.5	88.8	0.6	89.8
		NH <sub>4</sub>	0.3	78.4	0.5	76.2	0.7	77.3	0.6	77.3
		NIL	0.1	38.7	0.8	43.2	0.7	39.9	0.5	35.6
9 LaCorey	25	NO <sub>3</sub>	0.5	105.4	0.7	106.1	0.5	106.1	1.0	104.3
		NH <sub>4</sub>	0.4	88.7	1.0	89.4	0.6	88.2	0.4	90.9
		NIL	0.3	54.0	0.5	59.0	0.8	62.0	0.2	58.1
10 Breton	50	NO <sub>3</sub>	0.5	60.3	0.3	61.9	0.4	61.8	0.3	60.2
		NH <sub>4</sub>	0.3	50.0	0.6	48.8	0.4	49.7	0.3	49.6
		NIL	0.2	16.2	0.2	17.0	0.2	15.9	0.1	16.8
11 Athabasca	63	NO <sub>3</sub>	0.5	86.8	0.8	84.2	0.6	93.2	0.4	88.5
		NH <sub>4</sub>	0.5	74.0	0.6	70.5	0.8	74.1	0.6	71.7
		NIL	0.5	39.3	0.7	40.1	0.6	41.7	0.6	39.5
12 Jarvie	260	NO <sub>3</sub>	0.6	111.2	0.2	97.0	0.5	102.1	0.3	106.3
		NH <sub>4</sub>	0.3	68.6	0.5	71.2	0.8	66.1	0.3	68.6
		NIL	0.7	53.9	0.5	53.7	0.8	51.2	0.4	55.4

<sup>a</sup> N applied at 50 ppm





APPENDIX F.    CONTENT (ppm) OF AMMONIUM AND NITRATE NITROGEN FROM FOUR SOILS SUPPLIED WITH K AND TWO SOURCES OF N AND INCUBATED FOR 35 DAYS (Third incubation experiment)

		Replicate													
		I				II				III				IV	
Soils	Ammonium fixing capacity ppm	Source of K <sup>a</sup> applied <sup>a</sup>	Source of N <sup>b</sup> applied <sup>b</sup>	NH <sub>4</sub>		NO <sub>3</sub>		NH <sub>4</sub>		NO <sub>3</sub>		NH <sub>4</sub>		NO <sub>3</sub>	
1 Fawcett	7	KCl	NO <sub>3</sub>	0.7	93.1	0.7	92.9	0.5	95.3	0.4	88.2				
		KCl	NH <sub>4</sub>	0.3	80.2	0.5	84.5	0.5	85.2	0.8	80.9				
		KCl	NIL	0.3	38.0	0.5	44.9	0.2	42.3	0.2	43.5				
		NIL	NIL	0.5	34.0	0.7	44.2	0.2	43.9	0.4	45.1				
4 Angus Ridge	48	KCl	NO <sub>3</sub>	0.8	112.9	0.7	108.5	0.7	110.4	0.8	97.0				
		KCl	NH <sub>4</sub>	0.7	94.9	0.7	98.4	0.5	96.8	0.6	88.0				
		KCl	NIL	0.4	53.1	0.7	51.8	0.5	57.0	0.6	45.8				
		NIL	NIL	0.2	44.5	0.4	54.4	0.3	53.3	0.5	42.3				
6 MaJean	112	KCl	NO <sub>3</sub>	0.7	98.7	0.7	108.6	0.5	95.2	0.8	93.1				
		KCl	NH <sub>4</sub>	0.8	81.6	0.6	76.4	1.2	75.2	1.1	81.6				
		KCl	NIL	0.6	31.3	0.4	43.4	0.5	43.7	0.3	45.6				
		NIL	NIL	0.2	53.7	0.5	56.7	0.7	57.9	0.7	60.8				
12 Jarvie	260	KCl	NO <sub>3</sub>	0.7	106.3	0.4	95.5	0.3	108.0	0.5	111.0				
		KCl	NH <sub>4</sub>	0.6	67.8	0.4	64.7	0.5	61.0	0.6	62.6				
		KCl	NIL	0.5	46.5	0.5	50.9	0.7	45.8	0.7	49.2				
		NIL	NIL	0.7	54.2	0.5	53.9	0.8	51.5	0.4	55.7				



APPENDIX G

NUTRIENT SOLUTION

$\text{NH}_4\text{Cl}$  and  $\text{NaNO}_3$  for N at 3.5, 7, 14 and 84 ppm

$\text{KH}_2\text{PO}_4$  29.00 g

$\text{NaCl}$  5.80 g

$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  29.00 g

$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$  29.00 g

Fe - EDTA 132 ml

$\text{H}_3\text{BO}_3$  58 mg

$\text{MnSO}_4 \cdot \text{H}_2\text{O}$  90 mg

$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$  51 mg

$\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$  30 mg

$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  0.7 mg

$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$  1.4 mg

Distilled  $\text{H}_2\text{O}$  132 liters

Preparation of Fe - EDTA solution:

4.39 g Ferric citrate and 5.53 g Disodium

EDTA ( $\text{Na}_2\text{C}_{10}\text{H}_{14}\text{O}_8\text{N}_2 \cdot 2\text{H}_2\text{O}$ ) autoclaved in 500 ml

distilled  $\text{H}_2\text{O}$  for 25 minutes at  $107.2^\circ\text{C}$  and  
 $1.05\text{ kg/cm}^2$  pressure ( $225^\circ\text{F}$  and 15 psi).

1 ml/liter of solution for 1.6 ppm Fe.











**B29993**